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JOURNAL OF

THE INSTITUTE OF PETROLEUM

FOUNDED 1913 INCORPORATED 1914

Vol. 34 NOVEMBER 1948 No. 299

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Published by the Institute of Petroleum.
Address: "Maxwell House," 26, Portland Place, London, W.1.
Telephone No.: LANgham 2250.
Telegraphic Address: Instpetech, Westdo, London.
Printed in Great Britain by Richard Clay and Company, Ltd., Bungay, Suffolk.

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Vol. 34. No. 299. November 1948.

EMULSIONS OF SEAWATER IN ADMIRALTY FUEL OIL WITH SPECIAL REFERENCE TO THEIR DEMULSIFICATION

By A. S. C. Lawrence (Fellow) and W. Killner.

Summary.

The problem of emulsification of seawater in Admiralty fuel oil is described, and the deleterious effects of these emulsions in H.M. ships and oil-fuel depots indicated briefly. The significant properties of the emulsions are described. A theory of emulsion stability is developed and, correspondingly, the conditions for demulsification laid down. The emulsifying agent was found to be contained in the whole asphalt fraction of the oil, and proofs were carried out to show that this material is responsible. The mechanism of breaking these emulsions by addition of surface-active agents and by fluxing additives is described, and the conditions for their most efficient and proper use worked out. Successful application to large-scale trials on shore and at sea are recorded; and one semi-large-scale rendering of unpumpable sludge pumpable is reported. A brief discussion indicates that the success of the work and of the theoretical approach upon which it is based challenge several basic conceptions of emulsions and demulsification at present generally accepted. A new sampling pot and a modification of the Dean and Stark apparatus designed for use at sea are described.

Present-day fuel oils emulsify water readily and form mixtures of great stability. Pre-war Admiralty fuel oil did not emulsify, and any adventitious water which did not settle out was present in the form of large "slugs" which were readily detected at the sprayers when the oil was burned. Emulsions did, however, form in the double bottoms of merchant ships. The emulsion varies from wet oil, containing from 1 to about 20 per cent, to real "sludge," which may contain up to the theoretical limit of 74 per cent—the value for a close-packed (hexagonal) assemblage of spheres. Seawater in fuel oil is objectionable for almost all purposes, although the loss of B.Th.U. is the least important owing to the high calorific value of the oil compared with the latent heat of evaporation of water. The salt in the water has deleterious effects upon the furnace refractories and also appears to be the cause of formation of the so-called "bonded deposits" on the boiler tubes.* When the water content is high, the consistency of the emulsions is great and they may become unpumpable. The fine dispersion of the water in the emulsions, especially after pumping, allows steady burning without indications of spitting at the sprayers, so that oil containing large amounts of water is burned without suspicion of the contamination. In one case examined, 10 per cent of seawater was found in oil being burned, although the engineer officers were confident that it was dry. Methods of detecting water which depend upon its sedimentation in bulk at the bottoms of tanks fail completely to detect emulsified water.

Emulsification takes place very easily. Water added in small amounts is readily stirred into finely dispersed emulsion. As the amount of water

* This aspect of the problem has been described fully in a recent paper by C. J. Gray and W. Killner (*Trans. Inst. mar. Engrs*, 1948, **60**, 43–54).

approaches the 74 per cent limit, the consistency becomes great and the shearing effect of stirring produces a system with a drop diameter of about 2·5 μ. The uniformity of diameter is noticeable. At this stage the emulsion has lightened in colour until it resembles cocoa. On standing, the emulsion coarsens until the diameter reaches about 25 μ, after which little change occurs. The viscosity falls considerably. Very concentrated emulsions, however, assume a " livery " consistency on standing. If large amounts of water are added initially, stirring causes the oil to ride round on top of the water, and emulsification does not occur rapidly until most of the water has been worked into coarse emulsion. Even so, under these conditions in naval ships, the motion of the vessel causes emulsification. In a cruiser in a moderate sea, causing a roll of about 5 degrees, together with turns at high speed, oil floating on top of ballast water emulsified 43 per cent in three days. Rolling is very efficient in promoting emulsification, since each roll involves squeezing out a layer of water between the bulk oil and that adhering to the sides of the tanks. Any subsequent pumping of the emulsion increases the dispersion of the water and homogenizes it. The origin of the water was ballast or underwater leaks. The former was liable to occur at all stages from acceptance of cargoes by tankers to burning in the ships. In a considerable number of naval vessels, water came into contact with the oil as part of the ship's operational procedure. Underwater leaks were another cause of contamination, especially in destroyers, but tankers are normally immune from this trouble, since the level of the oil in their tanks is above the water-line and only outward leaks of oil occur. In one tanker, examined after crossing the Atlantic, when she was partly pumped out and in the high position, tanks showing oil leaks on the hull contained oil which was drier than that in some of the tight tanks. Rarely, leaky steam coils cause contamination by fresh water. Analysis of a typical fairly bad sludge gave the following results :—

	Calculated on sludge, %.	Calculated on dry oil, %.
Water	62·0	—
Hard asphalt	1·31	3·48
Carbonaceous matter	0·55	1·45
Wax	0·23	0·6
Ash	0·30	0·8 (mainly Fe_2O_3)

The water was determined by the Dean and Stark method.[1] The residue from the water determination was filtered, and the salt remaining on the filter estimated in the usual manner after washing free from oil. It will be seen later that it is important to know whether the contamination is sea or fresh water.

Emulsified water was also a source of serious embarrassment to oil-fuel depots. The rapid rate of turnover in wartime gave no opportunity for reducing the water content by settling; the analytical control of water content was rendered inadequate by the layering of oils of different water content. Oils pumped into a large tank would have an erratic variation of water with depth owing to the chance arrival of wet or dry oil at any particular level. An example is given on p. 846. The rate of sedimentation of

this water was very slow. Large tanks would need to be sampled perhaps every 6 in before an average could be obtained which really represented the true value. This was impossible, and only sampling at top, middle, and bottom of even the largest tanks could be done. In the case of ships oiling at sea, there was no control over the water content of the oil after the oiler had left port.

It was also well known that much crude oil reaches the surface heavily contaminated by emulsified water, often brine. Egloff [2] estimates the amount as more than 400 million brl in 1940, which is about 20 per cent of the world's production. The passage of the oil up through the well at a high rate of shear, frequently agitated by gas liberated as the hydrostatic pressure falls, causes efficient emulsification of water which may not be emulsified in the oil pool at the bottom of the well. Any pumping operation aids the emulsification. Oil emulsions have been given a variety of names; *e.g.*, "roily oil"; "B.S.," short for "bottom settlings"; "sludge." Concentrated systems are named "tight" and dilute ones "loose," corresponding with the scientist's "close-packed" and "loose-packed," and with engineers' "unpumpable sludge" (R.N.: "thickers") and "sludge." Bottom settlings are concentrated emulsion plus a variety of other contaminants, including hard asphalt, soft asphalt, wax, mud, scale, and sand. Wax is particularly objectionable in marine practice as, in cold weather, it causes the emulsion to set to a semi-solid leathery mass which is unpumpable and not liquefied by stationary steam coils on account of the lack of convection and small thermal conductivity of the system.

The cause of emulsification of water (frequently brine) in crude oils and of the stability of the emulsions has often been discussed. It is generally attributed in a vague way to the asphaltic constituents. No attempt, however, seems ever to have been made to test this explanation experimentally nor to identify the emulsifying agent and explain its efficiency.[3–9]

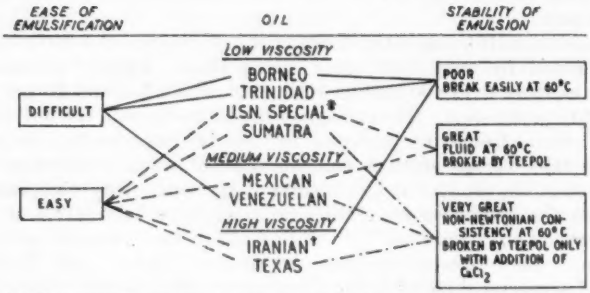
Many wetting agents have been patented or sold as proprietary agents, but they have fallen into some disrepute owing to erratic failures which have been attributed to the nature of the oil phase. This attribution of specificity of a wetting agent for a particular type of oil ignores other differences of composition of the emulsions which are of fundamental importance.

Effect of the Nature of the Oil upon Emulsion Characteristics.

So far, and in the experiments made later in the paper, the same sample of Admiralty fuel oil was used. This was a Venezuelan oil.

At this stage a number of other fuel oils were examined. It was confirmed that the ease of emulsification of water generally increases with increase of viscosity of the oil, but the stability of the emulsion is not directly related to ease of emulsification. Of the oils tested, those from Borneo, Trinidad, Iran, and Sumatra were pre-war samples, straight-run and of good colour. Fig. 1 shows the results of these qualitative tests diagrammatically. Fig. 2 shows results for some modern fuel oils. With these emulsions, consistency was judged qualitatively by rate of flow, which varied over a wide range, and the figures by which the consistency is assessed in column 1 do not, of course, imply equal increments between

each number. Fig. 2 shows clearly that there is no correlation between emulsion consistency and stability. They do show clearly, however, that emulsion stability increases markedly with the extent of cracking of the oil stock. Fig. 3 shows an attempt to correlate film-drainage rates with emul-



* Another sample was much more resistant to demulsification by Teepol.
† Pre-war.

FIG. 1.

EASE OF EMULSIFICATION OF SEAWATER BY FUEL OILS COMPARED WITH STABILITY OF EMULSIONS.

sion stability. It was thought that extra stability might be accompanied by viscous anomaly, and observations of the rate of drainage of the oils down the side of a bottle or down a glass plate confirmed that marked anomalies exist. Drainage varies from very rapid and so complete that the colour of the residual film is vanishingly small, to the extreme cases where drainage proceeds slowly to a point and thereafter ceases, leaving a

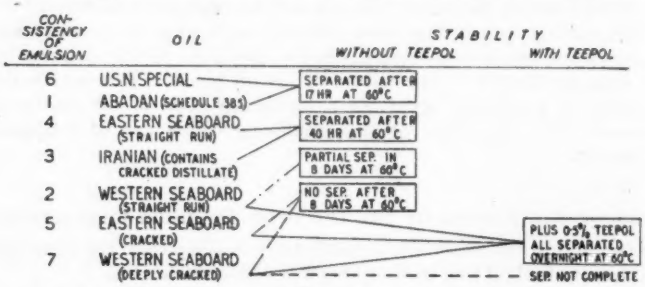

CONSISTENCY OF EMULSION
OIL
STABILITY
WITHOUT TEEPOL
WITH TEEPOL
6 U.S.N. SPECIAL
1 ABADAN (SCHEDULE 38S)
4 EASTERN SEABOARD (STRAIGHT RUN)
3 IRANIAN (CONTAINS CRACKED DISTILLATE)
2 WESTERN SEABOARD (STRAIGHT RUN)
5 EASTERN SEABOARD (CRACKED)
7 WESTERN SEABOARD (DEEPLY CRACKED)
SEPARATED AFTER 17 HR AT 60°C
SEPARATED AFTER 40 HR AT 60°C
PARTIAL SEP. IN 8 DAYS AT 60°C
NO SEP. AFTER 8 DAYS AT 60°C
PLUS 0·5% TEEPOL ALL SEPARATED OVERNIGHT AT 60°C
SEP. NOT COMPLETE

FIG. 2.

CONSISTENCY OF EMULSIONS IN DIFFERENT FUEL OILS COMPARED WITH STABILITY OF EMULSIONS.

permanent thick, dark-coloured film. As Fig. 3 shows, there is good correlation between this property and emulsion stability, especially in the extreme high and low rates.

It is also noticeable that the oils made up to a specified bulk viscosity between 1·3 and 2·0 on the arbitrary scale show an enormous range of film-drainage rates; and it is clear that the bulk viscosity gives no inform-

ation of the history and composition of the oil. Whether the bulk viscosity is reached by cutting back residual oil with gas oil or by a viscosity-reducing cracking, its value does not show how far the resultant oil is truly blended; that is, how far the lighter constituents are holding the heavier ones in solution and how far as suspension. Fig. 2 shows the deterioration following cracking and increasing the hard asphalt. Visual inhomogeneity was particularly marked in the partially drained films of U.S.N. Special and in the low-bulk-viscosity Sumatra oil. In the former, there is much black deposit, but in the latter it is in the form of larger brown gelatinous

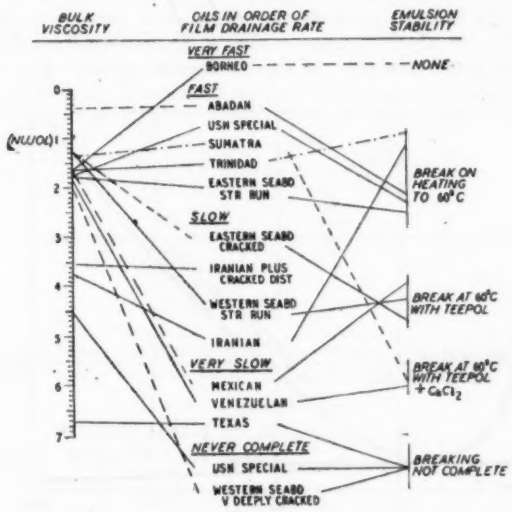


FIG. 3.

OIL FILM DRAINAGE RATES COMPARED WITH STABILITY OF EMULSIONS.

patches. The cracked Eastern Seaboard oil was particularly inhomogeneous. The Persian oil containing cracked distillate was markedly thixotropic in bulk. Fig 3 shows that there is lack of correlation between film-drainage rate and emulsion stability for the Sumatra and Iranian (both pre-war) oils. The Iranian oil contained the lub.-oil fraction, and its high viscosity was due to this as much as to its asphalt residuum. Its poor emulsion stability would appear to be due to this fact, which makes it a better balanced or blended oil in that there is not the marked discontinuity between relatively low-molecular-weight gas oil and high-molecular-weight asphalt.

THEORY OF EMULSION STABILITY.

It was found that after removal of hard asphalt and of organic acids, the recovered oil emulsified water as well as it did before treatment. Consideration was therefore given to the theoretical requirements of an emulsifying agent. Consider the simplest case of two immiscible liquids of equal

density, one dispersed in fine drops in the other. In the absence of any emulsifying agent and barrier to coalescence, the rate of separation will be determined solely by the collision frequency. This will depend upon the magnitude of the Brownian motion of the drops of the disperse phase, which is the only force causing collisions; and the initial separation of the particles, which depends upon the concentration of the disperse phase. The expression for the Brownian motion is :—

$$\frac{\bar{\xi}^2}{t} = \frac{RT}{3\pi N \eta r}$$

where $\bar{\xi}$ is the mean square displacement of a particle of radius r, in the time t, T is the absolute temperature, R the gas constant, N Avogadro's number, and η the viscosity of the continuous phase. Fig. 4 gives the

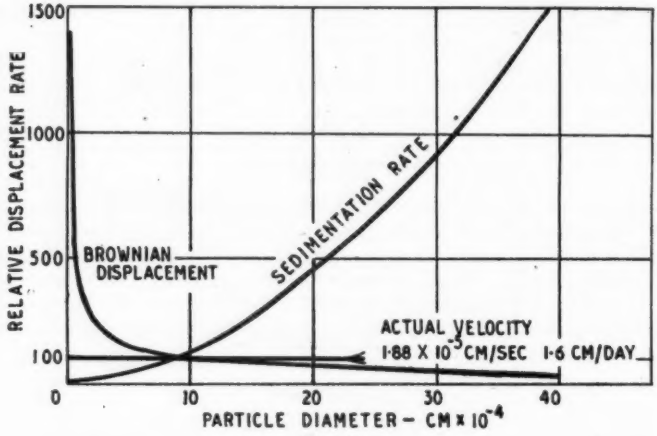


FIG. 4.

BROWNIAN DISPLACEMENT AND SEDIMENTATION VELOCITY PLOTTED AGAINST DROP DIAMETER—SEAWATER IN FUEL OIL.

values for the Brownian displacement in unit time for water droplets in Admiralty fuel oil. ($\eta = 2{\cdot}40$ c.g.s. units.)

The distance of separation of the droplets is obtained as follows. At high concentrations they are in close (hexagonal) packing. Consider the whole system to be made of an assemblage of close-packed spheres of diameter D. The centres of the droplets of the diameter d coincide with the centres of the spheres. Then the total volumes of the two phases, if there are n of each, will be :—

$$\frac{n\pi d^3}{6} \quad \text{and} \quad \frac{n\pi D^3}{6}$$

so that the volume concentration of the disperse phase is d^3/D^3. But the volume of the close-packed spheres of diameter D is only $\frac{\pi\sqrt{2}}{6}$ of the total

volume of the continuous phase and the true volume fraction ϕ represented by the droplets in the system is :—

$$\phi = \frac{\pi\sqrt{2}d^3}{6D^3}$$

The distance between the centres of the spheres and drops is

$$d\sqrt[3]{\frac{\pi\sqrt{2}}{6\phi}}$$

But S, the distance between the surfaces of the drops is $D - d$, which we may write as $d(f - 1)$ where f is $\sqrt[3]{\frac{\pi\sqrt{2}}{6\phi}}$.

Let us now equate S against ξ to give the mean time required for the original drops to meet to form double ones, the first stage in separation.

Then
$$d\left(\sqrt[3]{\frac{\pi\sqrt{2}}{6\phi}} - 1\right) = \sqrt[2]{\frac{2RTt}{3\pi N\eta d}} \quad . \quad . \quad . \quad . \quad (1)$$

or
$$d^2(f-1)^2 = \frac{2RTt}{3\pi N\eta d} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

therefore
$$t = \frac{3\pi N}{2RT}\eta d^3(f-1)^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Here the parameters are separated, those which are independent of the actual emulsion under consideration coming first, followed by the viscosity

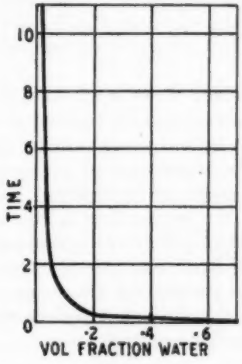


FIG. 5.

TIME REQUIRED FOR COLLISION AS A FUNCTION OF VOLUME FRACTION OF DISPERSE PHASE.

term for the disperse phase η, and then d and f which change with time in the separating mixture.

For Admiralty fuel oil, η is 240×10^{-2} c.g.s. units and d is $2{\cdot}5 \times 10^{-4}$ cm for freshly stirred emulsions. This gives the equation for the time required for the first pairing of primary droplets. Fig. 5 shows the values for t

for various values of ϕ. The full statistical treatment of coagulation has been given by von Smoluchowski.[10]

Now consider the case of the two liquids which have not the same density. The drops of the disperse phase will rise (as in milk) or fall (as with water in fuel oil) according to the direction of the gravity difference. The rate of fall, v, of a drop of water in fuel oil can be calculated from the Stokes equation :—

$$v = \frac{d^2(\Delta_1 - \Delta_2)g}{18\eta}$$

where g is the acceleration due to gravity, d the diameter of the drop, Δ_1 and Δ_2 the densities of water and oil respectively, and η the viscosity of the continuous phase. It is clear that there will be sedimentation downwards of the water drops in addition to the random Brownian motion. If the drops are all of the same size, sedimentation will not cause collisions but it will increase the collision rate by reducing the separation between the drops. Fig. 4 shows the sedimentation and Brownian displacements. The two become equal at a diameter of 10×10^{-4} cm for seawater in fuel oil. For drops smaller than this, therefore, Brownian motion is the rate of determining factor, but with large drops, the artificial increase of concentration at the bottom will cause coalescence to take place more rapidly than in the homogeneous system. In actual practice, another effect comes in, as all who carry out extractions with solvents will recognize. After the separating funnel has been shaken, separation starts mainly by a coarsening of the dispersion, and then the denser liquid begins to drop out faster and faster. As the drops fall they collect others in their path, and this sort of filtration effect still further accelerates separation, so that the rate of separation will not follow the curve in Fig. 5 for low concentrations when the original emulsion broken contains large amounts of water, but will be much more rapid.

Now consider the case where there is an emulsifying agent at the interface acting as an energy barrier and preventing coalescence when particles collide. This barrier may be electrical, arising from mutually repulsive like charges on the particles, or mechanical in those cases where the emulsifying agent is a highly viscous or rigid skin. Coalescence of drops will now only take place when the momentum of the colliding drops is greater than the value of the energy barrier. It is necessary to take into account the Maxwell distribution of Brownian velocities instead of using the mean-square displacement. The number of the drops n out of a total of n_0, having a Brownian velocity sufficient to overcome the energy barrier of value E is given by the familiar equation :—

$$\frac{n}{n_0} = e^{\frac{-E}{RT}}$$

From this we can say that no emulsion is ever completely stable, but for high values of E, the number of successful collisions will be so small that the emulsion is stable to all practicable tests. As the value of E is lowered so does the stability of the emulsion fall and the rate of coagulation increase until E is zero and all collisions are effective. Even at this stage, which is the first case considered, the rate of separation of the two phases

is dependent upon the collision rate. All other considerations being the same, it is obviously most difficult to accelerate the rate of separation of the most dilute emulsions where S is large.

It appears, therefore, that breaking an emulsion involves three processes which are distinct, and each with its own rate-determining parameters. The three processes are, however, interdependent, and the nature of the emulsion and the stage which breaking has reached at any moment decide which is the predominant rate-determining one. The processes are :—

(*a*) collisions,
(*b*) sedimentation,
(*c*) coalescence.

From equations 1 and 3, we see that collision frequency for a given emulsion can be increased by increasing temperature and by reducing the viscosity of the dispersion medium. Provided that the breaking is not

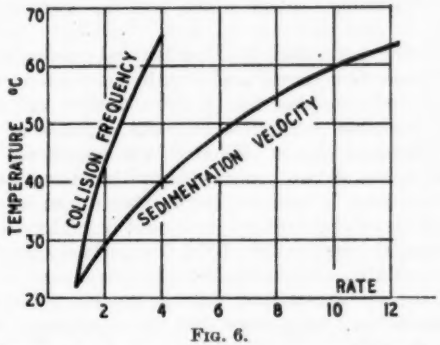


FIG. 6.

EFFECT OF TEMPERATURE UPON COLLISION FREQUENCY AND SEDIMENTATION VELOCITY.

carried out under pressure, 100° C is the upper limit which gives for the mean-square displacement an increase over that at 20° of 373/293, which is 1·4. The reduction of viscous resistance to the Brownian motion is greater and is for Admiralty fuel oil used five times. The two combined therefore give an increase for ξ^2 of seven times which is, for ξ, 2·65.

The Stokes equation shows that sedimentation velocity may be increased by increasing $g(\Delta_1 - \Delta_2)$ or by reducing η. g can be increased only by centrifuging and the scale of operation required rules this out. It should be noted in any case that centrifuging accelerates creaming and not breaking. The smallness of $(\Delta_1 - \Delta_2)$ means that a quite small change of either density will have a considerable effect. For the Admiralty fuel oil used in these experiments $(\Delta_1 - \Delta_2)$ was 0·0718 at 20° C and 0·1849 at 90°. Δ_2 was a linear function of temperature between 20° and 90° C. The reduction of the viscous resistance gives, as above, a five times acceleration. If $\Delta_1 - \Delta_2$ is increased by adding light oil, an additional reduction of viscosity will also be caused, but weighting the aqueous phase by a heavy salt will not give this additional acceleration.

Fig. 6 shows the accelerating effect of temperature upon Brownian motion

and therefore collision frequency; and upon sedimentation velocity. The results are calculated from the observed values of density and viscosity, and are shown relative to those at 21° C. The greater effect of temperature upon sedimentation rate means that the size of droplet at which sedimentation velocity begins to become the rate-determining factor will become smaller with rise of temperature. Maximum rate of coalescence requires that every collision should be effective, and this requires that the value of E, the energy barrier, should be reduced as far as possible. In effect, this means that the emulsifying agent must be removed or destroyed. Heating will usually have some slight destabilizing effect in so far as it will usually increase the solubility of the agent in the continuous phase so that the amount adsorbed at the interface will be reduced. But, in a very stable emulsion, such as these are, it is most unlikely that any such effect would be significant. If the emulsifying agent acted as a tough skin, heating might reduce its "toughness" and therefore its value of E; or, alternatively, a "fluxing" agent which had the same effect, could be used.

It is stated in the textbooks that emulsifying agents act by reducing the interfacial free-surface energy and so reducing the tendency to separation. It is suggested here that this is quite untrue and that the value of the interfacial tension determines only the amount of work required to disperse the internal phase. When it was considered that the first step in the coalescence of two spherical drops must involve a temporary increase of surface area, it appeared likely that a low interfacial tension would act as a demulsifying factor. It should be understood clearly that the suggestion that the magnitude of the free-surface energy is a measure of the *potential* instability or metastability of an emulsion is not questioned. However, the loose statement that this surface energy is a tendency to coagulation, without any suggestion that the mechanism of and rate of equilibriation is the rate-determining factor, is deplored. It is suggested further that there is a barrier to coagulation determined by the magnitude of the free-surface energy, so that this factor cancels itself out as a "tendency to coagulation." All emulsions (and hydrophobic sols) are regarded as metastable systems in which the rate of equilibriation (in this case, coagulation) is extremely small owing to the smallness of translatory kinetic motion which is, necessarily, a property of all colloid systems. It was found that wetting agents did, in fact, break emulsions and the enquiry then followed the two lines of finding the conditions for breaking the emulsions and the search for the emulsifying agent.

Following the idea that lowering the interfacial tension would aid coalescence, a number of wetting agents as well as ordinary soaps were tried. Several commercial surface-active substances of the long-chain-sulphate type gave excellent results.

With Calsoline, Invadin, and Teepol at a concentration of 0·13 per cent on a 70 per cent emulsion of water in fuel oil, complete separation was reached after heating for 1 hr, by which time the temperature had reached 110° F. Sodium oleate was also successful, but higher concentrations were required. Subsequent experiments were carried out mainly with Teepol owing to its ready availability in quantity. It was found that increasing the concentration of Teepol to 1 per cent gave partial separation at room temperature,

but that some heating was needed for completion. Smaller concentrations also gave complete separation when heating was continued for some hours, and the temperature needed increased with decrease of concentration of wetting agent. Difficulties arose in assessing the rate of separation under various conditions owing to the suspension of separation which occurred on occasions and apparently at random. Gentle stirring would then break the coarse emulsion which seemed to be held up by weak attachment to the side of the glass vessel, except at the bottom, where bulk aqueous Teepol solution had displaced the oil from the glass. It was also observed that pumping the emulsion facilitated separation.

Meanwhile attempts were made to break the emulsions by addition of organic liquids. It is well known that emulsions can be broken in this way, *e.g.*, those of oil in soaps by addition of alcohol, and its action is probably due to a combination of the two factors: increasing the solubility of the emulsifier in the continuous phase so that less is adsorbed; and, secondly, decreasing the polarity difference between the two liquids by the mutual solubility of the additive in both. Large amounts of the added liquid would seem to be required, and are required in the case of ethyl alcohol. There seems to be evidence that the matter is more complex than the conventional picture owing to the specific effects of additive upon the emulsifier changing its character by adsorption or loose complex formation. This requires much smaller amounts of additive, but the additives will be more specific in their action. With the water-in-fuel-oil emulsions there is not this usual hetero-polar emulsifier, and the action of organic liquids would appear to be a " fluxing " one, reducing the rigidity of the adsorbed layer and, by increasing its solubility in the oil, reducing the amount adsorbed. It is unlikely that any such action would appear with any additive at very low concentrations. The most efficient common liquid found was aniline, of which 2 per cent was required to break a 70 per cent water-in-oil emulsion. With cresol, *cyclo*hexanol, and benzyl alcohol 3 per cent was needed.

The Emulsifying Agent.

From what has been said already, it will be seen that a stable emulsion is one in which the value of E is so high that only a very small number of collisions are effective in bringing about coalescence. To break the emulsion, therefore, E must be reduced as far as possible. The magnitude of the viscous anomaly in the oil-fuel emulsions suggests that the emulsifying layer is one possessing marked toughness, but it must also be a substance such that it is adsorbed at the interface. This was an insurmountable difficulty at first, but gradually clues appeared, all tending in the direction of regarding the oil as half-way between a true solution and a suspension of the higher-molecular-weight asphaltic materials suspended in the lighter gas oil. This was supported by filtration experiments; by the observation that fuel oil heated and allowed to cool slowly in a beaker always formed a layer of very high viscosity on the bottom; and by the fact that oils allowed to drain down a glass surface showed a range of discontinuities from jelly-like small lumps to fine highly carbonized particles. The amount of adsorption in a system may be regarded as a partition between bulk and

surface, and the less soluble the adsorbed substance is in the bulk the greater will be the amount of adsorption, always provided that the substance has some surface activity.

In view of these observations and the failure of filtration experiment to give more than a partial separation, a vacuum distillation was carried out. No air leak was used, and the pressure was kept below 0·1 mm mercury pressure. After the middle oils had come over, the temperature rose fast and a small amount of wax came over, followed by an oil which became tacky on cooling. The distillation was stopped at this point. After cooling, the residue was dissolved in 5 volumes of petroleum ether and left to stand. The hard asphalt was filtered off in the usual manner, dried, and weighed. The soft asphalt was recovered by distilling the petroleum ether first at atmospheric pressure and then *in vacuo*.

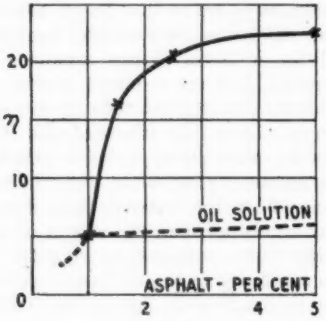


FIG. 7.

VISCOSITY OF EMULSIONS OF SEAWATER IN OILS AS A FUNCTION OF ASPHALT CONTENT.

It will be observed that the amount of petroleum ether used is less than that normally employed for estimation of hard asphalt, but after removal of the middle oils the amount used is equivalent to something approaching infinite dilution. For this reason, the hard asphalt is 3·5 per cent as opposed to about one tenth of this amount given by the normal test method [11] on the original oil. The results of this fractionation were :—

Middle and higher oils	65·0 per cent
Wax	0·5 ,,
Sticky oil	11·5 ,,
Soft asphalt	19·5 ,,
Hard asphalt	3·5 ,,

It will be observed that this distillation was carried much further under the low pressure than in the normal Engler method.[12] Solutions were then made up of the soft asphalt in Nujol, which was chosen as a base oil free from any emulsifying agents. Fig. 7 shows (broken curve) the effect of concentration upon the viscosity. Seawater was then stirred into solutions of the asphalt of various strengths in the ratio of 70 water : 30 oil, and the stability of the resultant emulsions observed with the following results :—

Concentration of asphalt in Nujol.	Behaviour.
10% soft asphalt	Stable emulsion; no separation after 3 days at 60° C
5% soft asphalt	Stable emulsion; no separation after 3 days at 60° C
2·5% soft asphalt	Stable emulsion
1·25% soft asphalt	Stable emulsion
0·75% soft asphalt	Emulsion showing slight separation after 3 days at 60° C
0·5% soft asphalt	Impossible to emulsify all the water; emulsion broke slowly; 23% left after 10 days at 20° C
3·5% hard asphalt	Stable emulsion; no separation after 3 days at 60° C
0·75% soft asphalt 0·13% hard asphalt	Emulsion showing slight separation after 3 days at 60° C

These emulsions have now stood at room temperature for more than 2 years without change other than a coarsening of the dispersion. It is clear that the fuel oil contains at least twenty-six times as much asphaltic material as the minimum required for the development of the full emulsifying properties. It is obviously quite out of the question to discard this amount on the supply position. It has been generally accepted in a vague way that emulsification is due to asphaltic materials, although no proof has been given that the emulsions are stabilized by an adsorbed layer of asphalt. Measurement of the amount adsorbed was therefore attempted. A 0·75 per cent solution in Nujol of the asphalt from the vacuum distillation was used. One third of the theoretical 74 per cent of seawater was emulsified in it by the usual stirring method. The mixture was left to stand and, after 3 days, sufficient free oil had separated at the top to pipette off a small amount, dilute it with benzene, and compare its strength with that of the original solution colorimetrically. The reduction found was from 0·75 to 0·66 per cent. An additional amount of water, equal to the first amount, was then stirred in and the mixture left to stand again. This time the analysis showed 0·52 per cent remaining in the oil and therefore 0·23 per cent adsorbed. The difference between the two amounts adsorbed—0·09 and 0·14 per cent—is not good, but the results prove definitely that adsorption occurs. Colour matching is easy at a dilution of 0·005 per cent of asphalt, but care needs to be taken that all the benzene used is of the same colour, as there are marked differences in laboratory specimens. The mean water-droplet size was 3μ after the separation, and the emulsions were remarkably monodisperse. This gives the thickness of the adsorbed layer as 2·47 Å. (for the total adsorbed after the second experiment). This thickness is rather small compared with the usual values for long-chain amphipathic emulsifiers, but a smaller value would be expected from the idea that asphalt is built up of *cyclo*paraffin rings if these lie flat at the interface. It should be noted also that this method of measuring adsorption assumes that the mass present is a linear function of the colour, which is most improbable. It would be expected that the most easily adsorbed material would be that with the darkest colour, but a solvent-separation experiment in which asphalt was shaken up with equal volumes of aniline and petroleum ether provided the rather surprising result that the light aniline extract was resinous, whilst the very dark petroleum-soluble one was oily. This suggests that the estimated thickness of the adsorbed layer judged from the colorimetric method gives a result which is too low.

A solution of the asphalt in petroleum ether or in benzene spreads readily to form a very thin film on a clean water surface. The film is invisible, but, when compressed by a slider, puckers and shows considerable rigidity.

The mechanical properties of the film at the interface are the cause of the viscous anomaly and high consistency of the emulsions. Each droplet of water is enclosed, as it were, in an elastic bag; laminar flow requires that the water droplets slip past one another, but they cannot do this at higher concentrations except by being elongated each time they pass their neighbours. This stretching of the "elastic bag" dissipates work which would be normally employed in driving the system in laminar flow. When the droplet has passed its neighbours, it relaxes to spherical form and dissipates some further energy by causing a minute local turbulence. There is therefore a double dissipation of energy supplied as the shearing force each time a water droplet slips past its neighbours, and the consistency of the emulsion is thereby increased. Another peculiarity can be predicted and was found. Increasing the dispersion of the water, for example by pumping, will increase the total interfacial area of "elastic bag" requiring to be stretched for a given volume of flow in proportion to $1/d$.

It has been shown that, while the original fuel oil contains 25 per cent of asphalt, 0·75 per cent only is enough to form a stable emulsion. It has also been shown that the formation of emulsions is due to adsorption of a film of asphalt at the interface and it has been postulated that the high viscosity of the emulsions is due to the rigidity of the adsorbed interfacial film. If emulsions are made up using the same amount of water in each case but increasing the concentration of asphalt in the oil, the viscosity of the emulsions should reach a maximum when the concentration of asphalt in the oil is sufficient to give a complete interfacial layer, and further addition of asphalt to the oil should produce no significant increase in the viscosity of emulsions. Fig. 7 shows that this is so. The broken line shows the effect of asphalt concentration upon the viscosity of the oil, and the full line that of emulsions of 70 per cent of water in it. It will be noted that the maximum viscosity requires more than 0·75 per cent, a fact which is not surprising in view of the smallness of the amount determined in the adsorbed layer. Adsorption is clearly complete by the time that the concentration has reached about 2·5 per cent.

From these experiments, therefore, it is learned that asphalt is the emulsifying agent; that it is adsorbed readily; that it spreads readily from benzene solution on water and that it forms a "tough skin" at the oil-water interface. The great stability of the emulsions is therefore explained, although the reason why asphalt should show hydrophilic properties is still obscure. The interfacial tension between the phases of these emulsions is remarkably high, and the ease of adsorption of the asphalt must therefore be attributed largely to its low solubility in the oil. The oil is regarded as an imperfect solution in which the high-molecular-weight asphaltic material is suspended in the lighter fractions of the oil. The least-soluble portion of the asphalt, which comprises the so-called "hard asphalt," forms the core of an onion-like particle.[14] On the core will be adsorbed the next-lower-molecular-weight materials and so on. In an ideally blended fuel oil, there would be continuity from the core

down to the lightest components, but fuel oils are not ideal, and there is a big gap between the heavy asphaltic matter and the lighter gas oil, the missing "layers of the onion" being the lub.-oil range. Further complications will ensue when the solvent properties of the gas oil for the asphalt change. Mixing of fuel oils will therefore be likely to alter these solubility relationships and make the "onions" more or less soluble and also to add on or take away a few outer layers. Of course, the onion layers are not sharply separated, but merge continuously each into its neighbour throughout the particles. Fig. 8 shows the amount of "asphalt"

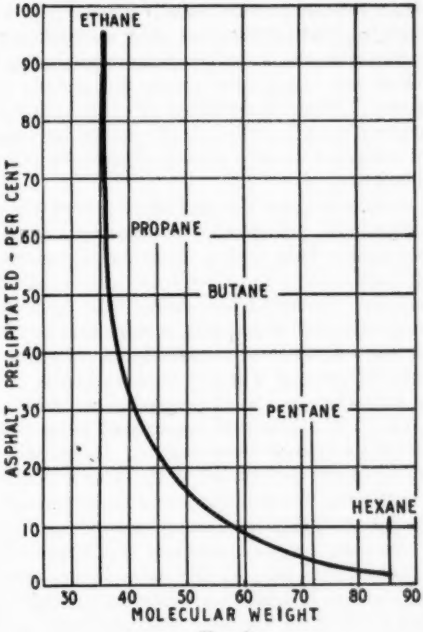


FIG. 8.

DE-ASPHALTING OILS BY HOMOLOGOUS HYDROCARBONS.

precipitated from an oil by the homologous paraffins.[15] On the onion model, the lightest solvents will remove only the outer layers, and as we ascend the series more and more layers are removed. This model is similar to that associated with the name of Nellensteyn, who, however, made the unacceptable assumption of a core of graphite.

The pre-war Iranian oil, which did not emulsify, was a better-balanced one, containing little very-light-molecular-weight asphalt and retaining the lub. range of oil missing from present-day fuel oils.

Asphalt has all the characteristics of a polymer of not very great molecular weight and not possessing marked indications of a linear structure. The components separated by numerous workers and generally accepted as a

basis of classification are asphaltenes, neutral resins and carboids, together with insignificant amounts of asphaltogenic acids.[16] The carboids or "free carbon" are heavily dehydrogenated highly condensed material which always results from pyrolysis of carbon compounds. They exist only in very heavily cracked material and are insoluble in organic solvents. The main bulk of the asphalt is made up of the resins and asphaltenes. It is probable that both belong to the same polymer homologous series, the resins being the lower members with some volatility. The distinction customarily drawn between the two is based on the somewhat unreliable method of solvent separation. The asphaltenes are insoluble in petroleum ether, whereas the resins are soluble and are usually removed by adsorption upon a suitable adsorbent from which they are then washed out. In distillates lighter than the heaviest fractions, only resins are present and are the origin of the colour of these oils. Asphaltic products normally contain oxygen, sulphur, and nitrogen. There is evidence of connexion between asphalts and polycyclic hydrocarbons, but the actual relation between them is quite obscure. Neutral resins are readily converted into asphaltenes by heating in the presence of oxygen.

The resins are adsorbed upon the asphaltenes very readily; or, if the asphaltenes are already in solution, it is better to regard the mixture as a non-ideal solution. This is the accurate statement of the onion model; that with increase in size of molecule very great deviations from ideal behaviour set in. Brønsted has shown that such deviations occur with molecular weights as low as those of hexane and hexadecane. There is no necessity for the existence of a central core of carbon or any solid, although such solids if present will act as adsorbents. The remarkable fact is established that the amount of precipitation caused by addition of liquid propane to an oil *increases* with increase of temperature, reaching a maximum just below its critical temperature. Gases also act as asphalt precipitants. This is easily understood if the action of the added hydrocarbon is one of rendering the solution more nearly ideal; *i.e.*, reducing the amount of association of large and small molecules in the oil mixture so that the smaller ones no longer solubilize the larger and intrinsically insoluble ones. That is, stripping off the outer layers of the onion. The ideal solution would be one in which the material forming the layers of the onion would be free of all other species; each molecule would be a kinetic unit moving free of association with any other. It should be noted that solutions showing great deviations from ideality are not necessarily colloidal, but do form a link between colloidal and true crystalloidal ones.

Emulsion Breaking.

Numerous experiments were carried out to determine the effects of concentration and temperature. It was found that there was a minimum concentration below which little or no breaking took place and that large increases above this had a progressively smaller effect upon rate of breaking. High temperature increased the rate. Accurate measurement of breaking rates were not, however, possible, owing to the way in which coarsening of the dispersion and partial separation of water in bulk was followed by masses of coarse emulsion "hanging up" as if by weak adhesion, to the

walls of the vessel. This habit was most marked in glass vessels of small diameter and was quite erratic. Gentle stirring caused these masses to break down at once into free water. Fig. 9 shows a typical set of results of rate of breaking when this effect was seen. The drop size in the " hanging-up " lumps was up to 1 mm. At this size, Brownian motion is vanishingly small, and collision will not therefore take place in the absence of external disturbance, even when the drops are in very close proximity. The cause of the " hanging up " was traced to the condition of the walls of the glass vessels. Breaking trials were made by adding Teepol to a batch of emulsion, and then pouring equal volumes into a number of beakers of the same diameter, all of which were ordinarily clean. The rates of breaking were widely different. The beakers were then chemically cleaned with hot chromic acid and the experiment repeated; all then broke at the same

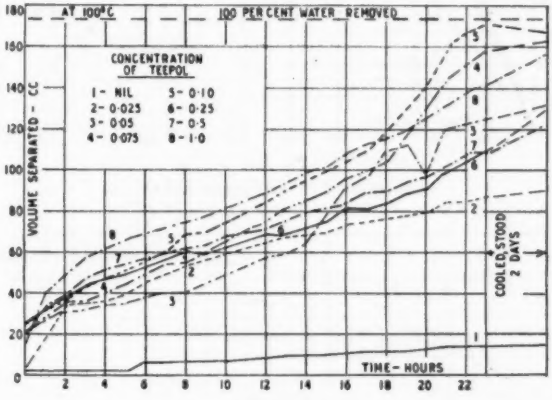


FIG. 9.

RATES OF BREAKING EMULSIONS; EFFECT OF CONCENTRATION OF TEEPOL.

rate. Later a simplification was found in which the beakers were washed with a little hot Teepol solution and swabbed round with a plug of cotton wool rinsed in hot water once and then left to drain. Figs. 10 and 11 show the results of trials carried out in vessels cleaned in this manner; in the first set, a number of beakers of different diameter were filled to the same depth, and in the second set, the same volume was used in all with correspondingly different depths. It is clear that the wall effect has disappeared. A final drastic test was made in a tube only 7 mm in diameter, and on cleaning with Teepol no hanging-up occurred. The most dangerous method of cleaning is that of washing with white spirit, which may leave a film of hard asphalt too thin to be visible; this causes serious hanging-up. Large-scale trials never showed this effect, but rates could not be predicted from laboratory-scale experiments until it was eliminated.

If the wetting agent is acting by reducing the interfacial tension, it is clear that the minimum amount required must be not less than that required to produce a concentration in the total amount of water present equal to the

"critical" concentration. That is, the concentration of the wetting agent at which the assymptotic value of the surface or interfacial tension is reached and above which no significant further lowering occurs. To allow for initial interfacial adsorption, a small amount in excess of the

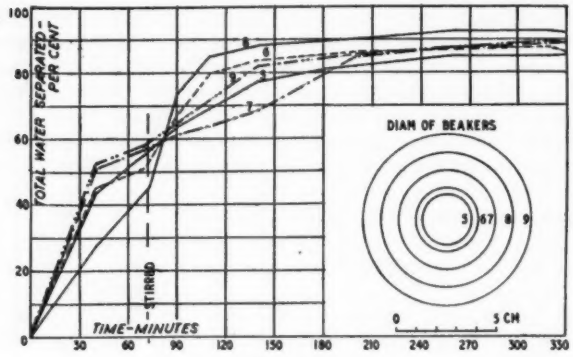


FIG. 10.

WALL EFFECT IN EMULSION BREAKING.

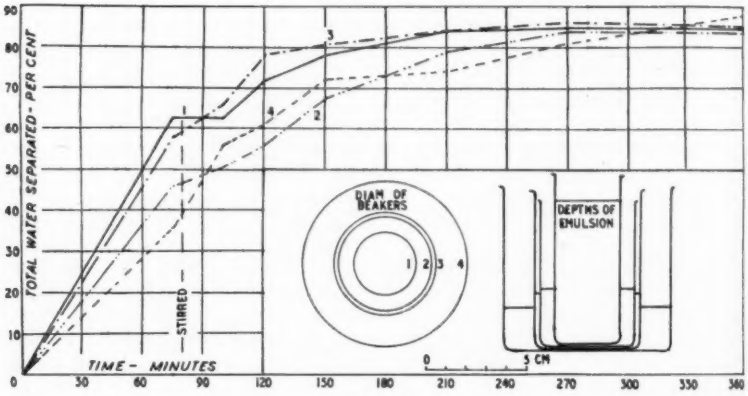


FIG. 11.

WALL EFFECT IN EMULSION BREAKING.

critical concentration will be required for maximum efficiency. Fig. 12 shows the surface tensions of solutions of Teepol in distilled and sea-water determined by the maximum-bubble-pressure method. The seawater results show the expected activation by the Mg ions and, in addition, marked ageing effects were observed at 0·75 per cent, that is, at the intermediate value between the surface tension of the water alone and the minimum where such effects have been reported for most surface-active

substances. The activation of Teepol solution of 1 g of the pure wetting agent per litre of water by calcium chloride has been reported by R. G. Aickin,[19] but the full activation is not yet reached with 1·5 per cent. These workers used interfacial tensions against hydrocarbons, and their lowest recorded value is just below 3 dynes. The value of the activating action of the polyvalent kations is apparent from Fig. 12, which shows that the concentration of Teepol required to reach the critical concentration is reduced to one tenth. The effect of concentration of Teepol upon ease of emulsification and its prevention were examined in two other ways. A layer of fuel oil about $\frac{1}{8}$ in in thickness lying on top of 500 cc of seawater was stirred by a looped wire with an up-and-down motion. Teepol was added

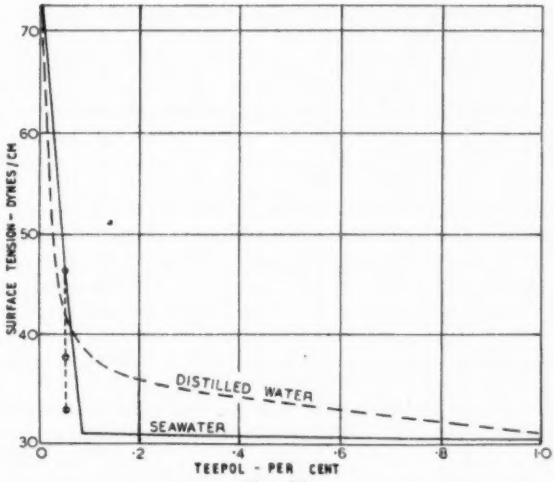


FIG. 12.

SURFACE TENSION/CONCENTRATIONS RESULTS FOR TEEPOL IN DISTILLED AND SEAWATER SOLUTION.

from a burette. The first effect was a reduction of the size of the oil drops carried down into the water until 0·38 cc had been added. The drops were then drawn out into fibrils, and at a fairly critical concentration the mixture took on a characteristic feathery appearance. Attempts were then made to emulsify seawater containing various amounts of Teepol. When the concentration reached 0·08 per cent a very marked reduction was seen. These experiments give the following values for the minimum critical concentration :—

Surface tension	0·08	cc in 100 cc seawater	
Emulsion breaking	0·075	,,	,,
Stirring test	0·076	,,	,,
Emulsification inhibition	0·08	,,	,,

When Teepol is added to an emulsion and stirred gently, the first effect observed is a great reduction of consistency; then, usually after a few

minutes, a layer of free water appears at the bottom. Measurements were therefore made of the change of viscosity of a breaking emulsion, especially with a view to providing information for its use in rendering unpumpable sludge in tank bottoms pumpable.

The emulsion was prepared by stirring 70 cc of seawater into 30 cc of

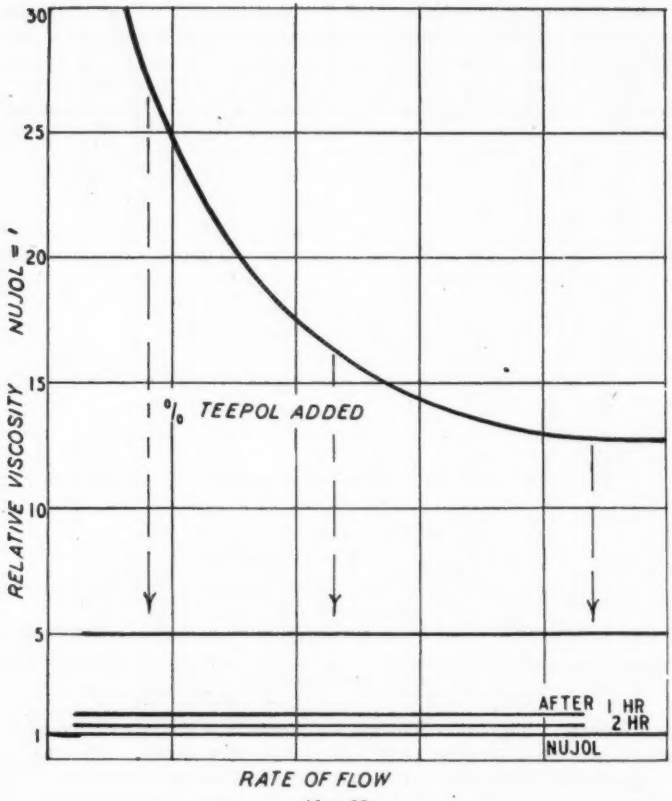


FIG. 13.

VISCOSITY CHANGES DURING BREAKING OF AN EMULSION BY TEEPOL.

oil in the usual manner. At these high concentrations of water, the consistency of the emulsion becomes great, and stirring produces great shearing force so that fine dispersion is assured and similar emulsion obtained on every occasion. The measurements were carried out at room temperature; consequently 1 per cent of Teepol was added. It was stirred gently until uniform. Fig. 13 shows the results. The upper curve is for the untreated emulsion and shows the usual large viscous anomaly. As soon as the Teepol was stirred in, the viscosity fell greatly and the anomaly

disappeared. At extremely small rates of shear there must still have been a small anomaly, but the apparatus used was not capable of working at such low rates of flow.

The values of the viscosity after 1 and 2 hours standing are also shown, at the end of which time it will be seen that the viscosity had fallen almost to that of the base oil. These results are most important for three reasons. First, they show that the penetration of the aqueous solution of Teepol through the continuous oil phase to the interface is rapid. In earlier stages of the work difficulty had been anticipated, and in the first large-scale trial at Old Kilpatrick (p. 842), where mixing was done by circulating the emulsion plus Teepol rapidly by the station pumps, discrete streams of water in the oil were seen in the return oil flow quite early, but circulation was continued until re-emulsification had taken place to a very fine state of dispersion which is recognized by the cocoa colour which it assumes. The mixture was then much more finely dispersed than at the start and therefore increased the time required for separation. Secondly, it showed that rendering unpumpable sludge pumpable without heating was possible. This was particularly important, since the high consistency of the material makes heating coils useless owing to lack of convection. Thirdly, it showed clearly the mechanism of the breaking. Since the viscous anomaly of the original emulsion is due to the mechanical strength of the asphalt emulsifying layer, then disappearance of the anomaly means that the more surface-active Teepol has displaced the asphalt and formed a layer of Teepol of insufficient concentration to re-emulsify the oil in the water. This replacement is similar to the effect of soap upon a saponin solution. A bubble blown of saponin in water wrinkles when air is sucked out from it because the saponin has the property of forming a semi-rigid adsorbed surface layer. When soap is added, its greater surface activity causes it to migrate to the surface and displace the saponin so that a bubble blown from a mixture behaves like one of soap alone in that it does not wrinkle when contracted.[20]

Obviously, the existence of the critical concentration of wetting agent in the water is important not only as defining the minimum required but also means that the amount to be used *must be calculated on the water content of the emulsion*. Experiments upon emulsions of various water contents, using in each case the amount of Teepol required to reach the critical concentration in the water present, confirmed this principle.

It is especially important when it is realized that a 10 per cent emulsion, for example, will require only one seventh of that required by a 70 per cent one; and that, if the amount were taken on the bulk of the emulsion, the 10 per cent one would have seven times too much Teepol. Not only would this be a gross waste but it also causes re-emulsification of oil in the excess of aqueous Teepol. Any demulsifier will be an emulsifier at some higher concentration, but the gap between the critical concentration and that at which it begins to act as an efficient emulsifier cannot yet be laid down theoretically. It can, however, be said that the gap will be largest for those wetting agents giving the steepest surface tension–concentration curves and vice versa. In general also the best wetting agents will be the best demulsifiers, whereas the best detergents will be the best emulsifiers. Wetting and demulsification require a small soluble molecule which forms adsorbed film with no rigidity,

whereas the emulsifier and detergent need the higher homologues with less solubility and giving solid or semi-solid surface layers.

Heating is not necessary with some emulsions provided that a larger concentration of Teepol is used. The reason for this greater activity of the higher concentration is not clear, but the accelerating effect of heating when the critical concentration is used is simple. As already explained, the adsorbed asphalt as well as the large excess in the oil not adsorbed has a poor solubility and may be expected to retard both collision velocity and sedimentation rate. Heating is required to take it into solution, and the minimum temperature to which an emulsion needs to be raised for rapid breaking should vary with the nature of the oil. This part of the acceleration influence of heat is quite distinct from those computed in section 4. This is confirmed by the acceleration of breaking brought about by addition of good solvents for asphalt such as benzene. The increase of rate of breaking is considerably greater than that due to the decrease of the viscosity of the oil and the increase of the density difference between the two liquids. One emulsion has been met which broke easily with Teepol when thinned with benzene, but which became more stable on thinning with the same amount of petroleum ether as was anticipated from its poor solvent action on the hard asphalt.

Large-scale Trials.

The first large-scale trial was carried out upon a 12-ton lot at the Admiralty oil-fuel depot, Old Kilpatrick, by the kindness of the Officer-in-charge, Mr. Tew, to whom the authors are indebted for much help and information. The operation was carried out in a 20-ton tank of approximately cubical shape, fitted with steam heating coils. Mixing was done by the station pumps. The exterior temperature was in the neighbourhood of 32° F throughout and, initially, the tank contained 17·34 tons of emulsion (7 ft 7 in depth). This was of a mixed origin, but much of it was depot sullage in which the water was melted snow. The mixture was heated overnight and by the morning the temperature had risen to 100° F and 2 ft 2 in of clear water had separated at the bottom. This was run off and the sample taken for analysis. The emulsion was also sampled, and water determinations made with the following results :—

Level, ft below surface.	Water, %.	Temperature, ° F.
1	37	130
2	40	—
3	52	144
4	68	156

The total amount of water was estimated at 6 tons and its analysis showed 0·007 g total solids per 100 ml with only traces of precipitate with silver nitrate. In view, therefore, of the absence of activating salts, 3 gal of Teepol was used equivalent to a final concentration in the water of 0·25 per cent. The Teepol was run in slowly from the top of the tank, mixing in with the stream of emulsion returned by the pumps. After 5 min, clear streams of water were seen in the returning mixture, but circulation was

continued because at this stage time lag in the distribution of the Teepol throughout the emulsion was anticipated. The mixture then became more finely dispersed until it assumed the usual cocoa colour and its consistency increased. At this stage the temperature was 137° F and uniform; pumping was stopped and the heating cut off. The duration of pumping was sufficient to turn the whole mixture over twice at high pumping rate. Samples were taken off and treated with additional amounts of Teepol and kept warm overnight. In the morning almost complete separation had taken place in these samples, but 1 per cent of Teepol was no better than 0·5 per cent. The distribution of water in the tank was as follows :—

Level.	Water, %.
1 ft below surface	0·5
2 ft " "	52
2 ft above bottom	60
1 ft " "	79

In view of the slow progress of the separation, circulation was restarted and an additional 3 gal of Teepol added, bringing up the total amount to 0·5 per cent. The mean temperature had fallen to 115° F. By the next morning good separation had taken place, and the water analysis results were :—

Level.	Water, %.	Temperature, ° F.
1 ft below surface	0·5	88
2 ft " "	0·6	—
2 ft 6 in "	3·0	133
2 ft 9 in "	32·5	—
3 ft "	Reaching clear water	
1 ft above bottom	100·0	155

2 ft 10 in of clear water had separated, which is 52·3 per cent of the original bulk. The tank was kept heated moderately overnight and by the next morning the percentage of water 2 ft 9 in below the surface had fallen to 7·5 and its temperature to 115° F. The results of this trial are shown graphically in Fig. 14.

The second trial was carried out at the Admiralty Fuel Experimental Station, Haslar, upon 500 gal of emulsion prepared by emulsifying 150 gal of fuel oil and 350 gal of seawater by combined air blowing and circulation of the agitated mixture by pumps. Suction was from the bottom of the tank and the return at the top at the opposite corner. At the start, only water circulated, but soon oil came through as thin emulsion which rapidly thickened up. Samples were withdrawn at the draincock on the air vessel of the pump and pumping and air blowing were stopped when emulsification was judged to be complete. The mixture was left to stand overnight. There was a small amount of free water at the bottom of the tank which showed at the draincock just above the bottom. By the morning no further water had separated and the emulsion was of high consistency. Steam was turned on in the heating coil, and circulation by pumping started up again. After 1½ hr a sample taken at the pump draincock was a thick

brown sludge at a temperature of 100° F. Steam was shut off and 0·5 gal of Teepol added, *i.e.*, 0·014 per cent on the water content of the emulsion.

The emulsion thinned immediately, the labouring of the pump was much

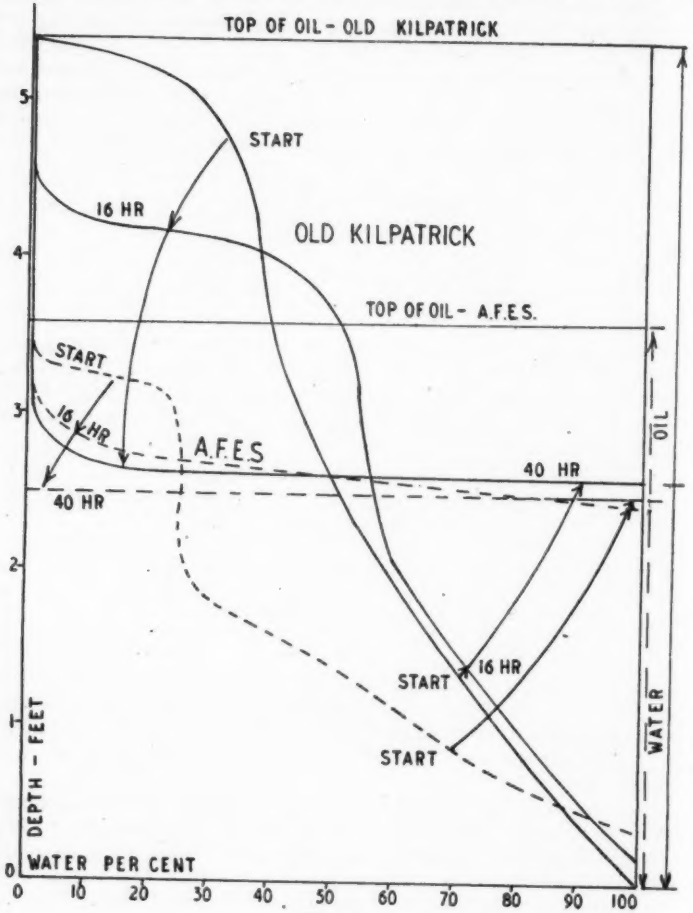


FIG. 14.

LARGE-SCALE BREAKING TRIALS.

reduced, and a sample taken at the pump draincock was black and fluid. The mixture was allowed to stand until the next morning, when 12 in depth of free water was found with 31 in of oil plus emulsion. Samples taken in various places in the emulsion showed patches of thick emulsion, especially around the heating coil, and the oil–water interface was not plane. The rate of circulation when the pump was not labouring was about 45 min to

turn the whole batch over. Steaming and circulating were restarted, but the only result was complete re-emulsification of all the water to thick brown sludge. A further half pint of Teepol was therefore added, bringing up the total concentration to 0·18 per cent calculated on the water present. This liquefied the system again and it was left to stand after 1 hour's pumping. On the next morning the results were :—

Level, inches below surface.	Water, %.	Level, inches below surface.	Water, %.
2	—	26	50
6	21·6	30	60
10	25	34	75
14	25	38	95
18	25	Bottom	Free water
22	30		

The samples taken at 10 in and below contain some free water. The mixture was heated until the temperature reached 110° F and it was then left to stand overnight. In the morning separation was complete. No emulsion layer could be detected at the interface and the 150 gal of dry oil was recovered quantitatively. These results are shown graphically in Fig. 14.

The third trial was carried out in a modern battleship, and was the first ever carried out at sea. The weather was good except on the last 16 hr of the separation, but the ship was making sharp turns at full power during the trials. The separation was carried out in a tank approx 16 ft deep and of about 30 tons capacity. It was situated in the Port harbour machinery room where the temperature was high. The tank was fitted with a steam heating coil near to the bottom. It was possible to withdraw the contents of the tank from the bottom and return them to the top by the sullage pump, via a funnel at which the Teepol could be run in slowly whilst the batch was circulated. A special and most efficient sampling "thief" was designed and made at AFES (see Appendix II), for taking specimens at exact depths. The water content of the emulsion was determined with the following results :—

Level.	Water, %.
1 ft below surface	0·6
4 ft above bottom	2·8
2 ft " "	10·0
1 ft " "	32·5

No free water on the bottom. From these figures graphical estimation gave a mean water content of 4·2 per cent. Four pints of Teepol were used, which is 0·25 per cent, the excess being taken to allow for underestimation of the total water, a factor which by this time was expected. It is clear from the above figures, that sampling would be required at every 2 in over the last 15 in depth. With the AFES pot the sampling would be possible, but in this case there was no time available for this extra sampling and analysis. The determination of water was made by the AFES modified

Dean and Stark apparatus which was found to operate most efficiently at sea (for description see Appendix II).

The mixture was circulated cold, and the Teepol added during pumping. Heating was started at the same time and kept on overnight. By this time the oil was at a mean temperature of 118° F, and the water analysis (after 16 hrs) was :—

Level, ft above bottom.	Water, %.
4	2·4
2	3·0
1	65·0
0·5	Free water

After standing a further 24 hr the temperature of the mixture had fallen to 103° F (centre) and the water content was :—

Level, ft above bottom.	Water, %.
14	0·5
12	0·7
8	0·6
4	0·7
3	0·6
2	0·7
1½	24·0
1	Free water

The final result after 46 hr is shown in Fig. 14. Of the oil, 90 per cent was recovered in a state fit for burning. Of the remainder, 9 tons of water was removed and the interface of emulsion remaining amounted to only about 1 ton. Subsequent operations were carried out in the battleship whilst in port, but the efficiency reached was not so good owing to inadequate heating due to lack of steam. The following table of the water distribution in one tank is as an example of the erratic distribution which is likely to occur and which makes the obtaining of a true average very difficult :—

Level, ft above bottom.	Water, %.	Level, ft above bottom.	Water, %.
16	3·0	7	26·0
15	11·0	6	28·0
14	11·0	5	18·0
13	12·0	4	20·0
12	18·0	3	8·4
11	9·6	2	36·0
10	20·0	1	35·0
9	28·0	Bottom	32·0
8	22·0	Total depth: 16 ft 7½ in.	

The fourth trial was carried out in H.M.L.S.T. 3502 under conditions of

considerable difficulty. The external temperature was very low; the tank available for separation was of large cross-sectional area compared with its depth—230 tons had a depth of only 9 ft 2 in. Connexions necessary for mixing by circulating with the ship's pumps were lacking, and the heating coil in tank 13 was inadequate to deal with the initial 270 tons of emulsion. There was a small amount of free water at the bottom, and a sample taken off for analysis of chloride content showed it to be seawater. It was decided to remove part of the emulsion to two smaller tanks, 8 and 11, to heat the three lots separately, add the Teepol required, and then pump the contents of 8 and 11 back into 13 for the sedimentation. After partitioning the emulsion in this manner, the three tanks were sampled and water determinations made with the following results :—

Level, above bottom.	Water, %.
Tank 11. Depth 9 ft 10 in	
9 ft 4 in	13·0
4 ft 10 in	15·5
2 ft 6 in	22·0
2 ft	90, free water
Bottom	Free water
Tank 8. Depth 9 ft 4 in.	
9 ft	3·0
5 ft 4 ins	15·0
7 ft	35·0
Bottom	Free water
Tank 13. Depth 5 ft 2½ in.	
2 ft 2½ in	4·0
2 ft 8½ in	5·5
11½ in	35·0
Bottom	Free water

The free water was discharged overboard and the amount of water in the remaining emulsion calculated as follows :—

Tank.	Water, tons.	Oil, tons.	Teepol required, gal.
8	15·2	68·8	7
11	6·8	31·2	3
13	9·2	138	4
Total	31·2	238	14

The Teepol is 0·02 per cent of the water present.

After heating up the emulsion to 90°, 90°, and 100° F in the three tanks and running in the Teepol, tanks 8 and 11 were pumped back to 13. The Teepol improved the pumpability. Air blowing was started in 13 and mixing was improved by " snaking " of the air line. Mixing, however, was through the only manhole available for working which was at one end of the tank. Heating was continued for a few hours and then all was shut down and left to stand. By the next morning (12 hr later) the temperature of the

oil was down to 68° F (the ship was cold and the water very cold) and it was sampled with the following results :—

Total depth 9 ft 2 in.

Level, above bottom.	Water, %.
Top	Dry
1 ft 6 in	40, free water; 20 in oil part of sample
1 ft 3 in	95
1 ft	Free water

Samples taken 24 hr later at 1 ft 9 in and 1 ft 3 in above the bottom contained 15 and 10 per cent of water respectively. There was 1 ft 2 in of free *i.e.*, water, 12·75 per cent or 30·5 tons. In the absence of any heating (all dry fuel oil had been consumed), the separation was stopped at this stage, *i.e.*, 98 per cent separation of water. These results are also shown graphically in Fig. 15.

Conclusions from Large-scale Trials.

It is clear that large-scale operation introduces no new factors into the emulsion breaking and that no special plant is needed. It is essential that adequate heating be available. The chief difficulty encountered is that of estimating the total amount of water in the emulsion at the start. This is particularly difficult in the common case where the concentration increases rapidly over the bottom 2 ft or so. The level of free water can usually be detected accurately and easily by water-detecting-paste, but there is no certainty that the oil–water interface is plane, especially when the oil is cold. The paste is also troublesome when the oil is cold. It will be noted that the estimate of the water is very accurate in the last trial after it had been realized what care was needed if Teepol was not to be wasted by using 100 per cent excess to compensate for possible underestimating. It will be observed that in the operation in the battleship about two thirds of the charge was only slightly contaminated. Wherever possible, sedimentation of the emulsion should be accelerated by heating, and the dry oil on top run off before the sludge concentrated at the bottom is given treatment with Teepol or other additive.

Rendering Unpumpable Sludge Pumpable.

An emulsion was made from 120 gal of Admiralty fuel oil and 360 gal of seawater at AFES. The amount of water is 75 per cent, which is in slight excess above that which can be emulsified. This gave the worst conditions for emulsification, which was carried out by air blowing followed by circulation. The air was blown through a simple rose at the bottom of the oil and, after 1 hr, the water content in the oil at the top above the rose was 62 per cent. After 4 hr blowing, circulation by pumping was started, suction being taken from the bottom south-east corner and the return to the top at the north-east corner. After 1½ hr the pump was still circulating water only. After standing overnight, 3 in of clear water was found on the bottom. This was drawn off at the draincock, at the south-west corner, reaching to

½ in above the bottom of the tank. 12 gal was run off. The emulsion was of high consistency, and a sample taken from the top showed 68 per cent of

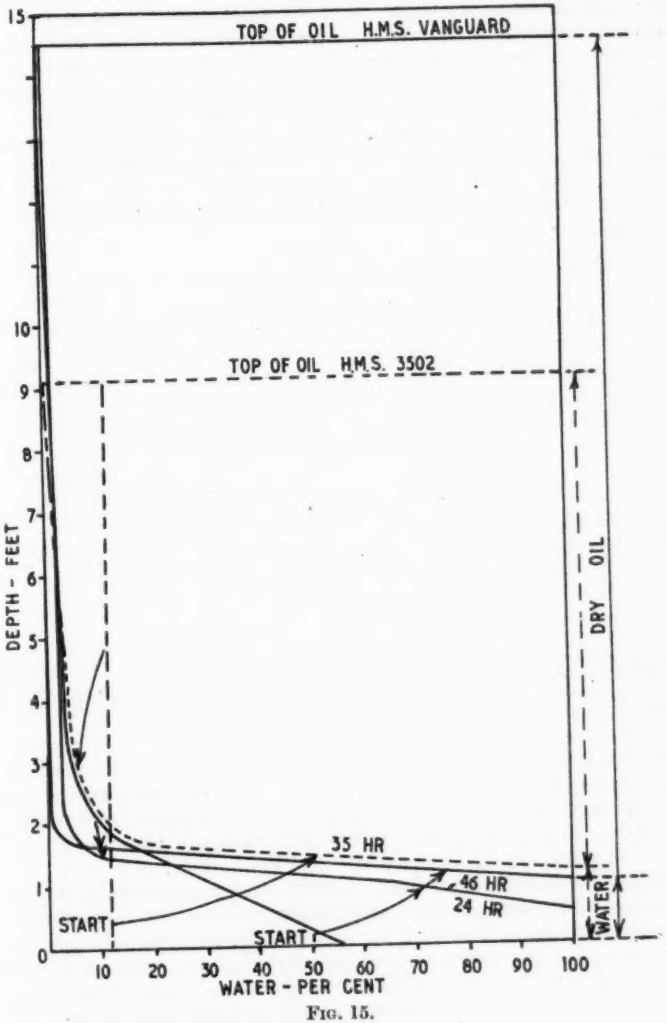


FIG. 15.

LARGE-SCALE BREAKING TRIALS.

water. Pumping was restarted, but only water was circulated. It became evident that the water was sucked out from the bottom, returned to the top opposite corner and had channelled a diagonal stream through the stiff

emulsion through which it was circulated. Water was therefore drawn off at the pump until oil began to flow. The emulsion then began to thicken fast, and the pump lost suction. The water content was 65 per cent and 410 gal remained in the tank. If all the remaining 290 gal of water were uniformly emulsified, the water content would be 70·5 per cent. On the next morning the mixture was of very high consistency; no water had separated in the night, and the mixture was a good case of unpumpable sludge. The temperature was 60° F and 0·1 per cent Teepol was sprinkled on the top; steam was admitted to the heating coil and air blowing was started after removing the rose to give the worst mixing conditions, such as might occur under conditions of improvisation in ships. The progress of the trial was followed by taking samples and measuring their viscosity. The results were :—

Time.	Sample.	Temp, ° F.	Viscosity.	
			Glass tube, sec.[1]	Redwood II, sec.
13.30	Air and steam on top centre	60	65	2850[2]
13.32	" " "	64	28	1230[2]
13.40	" " "	75	14	615
14.10	" " "	100	—	292
14.15	Bottom S.W.	90	No free water	
14.35	Top centre	110	Water showing at draincock	
	Top N.E.	115		
14.40 steam off	Top centre	113	—	163
15.10	Top S.E.	68		—
	Top N.E.	97		—
	Top E.	104		—
	Top S.W.	75		—
	Top N.W.	98		—

[1] Arbitrary units of viscosity measured in a glass efflux viscometer made up for the job and calibrated with reference to the Redwood II on the sample taken at 13.40.

[2] Extrapolated. The Redwood instrument would not flow with these very high-consistency mixtures.

It was clear that a steady state was being reached and the south side of the tank was not being heated adequately. This side was exposed to wind and was therefore cooling more rapidly than the others. At 15.20 the air pipe was moved to blow into the bottom north-west corner and at 15.25 to the south-west.

At 15.35 an attempt was made to start pumping, but the plunger stuck at the top of the first stroke. After turning over by leverage it continued to pump with heavy labouring for about 2 min, whereupon it then cleared very rapidly and worked freely. The initial heavy working took place whilst dealing with emulsion left in the cylinder and pipelines. A sample taken from the pump at 14.40 had a viscosity of 820 Redwood sec. Pumping was stopped at 12.45. Water separation started and in 24 hr, 10 in (about 25 per cent) had separated.

Several important lessons were learned from this trial. It showed well the remarkable ease with which water can channel a passage through oil and maintain it, especially when the oil is thickened by emulsification or by

any other cause such as high viscosity or wax and cold weather. This was easily stopped by placing a baffle beneath the returning stream. It showed that the mixing effect of the air blowing extended to a radius of only 2 ft to 2 ft 6 in around the rising air current. It is essential that the Teepol shall reach all the emulsion as quickly as possible and before water separation starts, since this carries the Teepol down with it. The obvious solution lies in moving the end of the air line about or having tail pieces on the end where this is possible. It also shows the need for stopping pumps as soon as they begin to labour and not waiting until they stop. These lessons were learned and applied successfuily in the trial in H.M.L.S.T. 3502 reported above.

Discussion.

The theoretical approach outlined here and the experimental support given to it by the emulsion-breaking experiments lead to two main conclusions, both of which are diametrically opposed to the ideas upon emulsions now generally accepted. The first is the general theoretical one to the effect that low interfacial tension is in itself enough to give stability to an emulsion stabilized by a surface-active emulsifying agent. The second is the idea that wetting agents act as emulsion breakers in a specific way, which is attributed to specificity of the agent for one or more oils and not for others.

The first idea comes from the classical work of Donnan and Potts,[21] who measured the interfacial tension of solutions in water of the sodium salts of the monobasic carboxylic acids against oil. They found that surface activity started with caprylic acid and increased rapidly with the higher fatty acids; and that emulsifying efficiency went parallel with interfacial tension lowering. They also pointed out that emulsifying power sets in at the concentration where micelle formation begins. This, however, is not true. For example, micelle formation starts with Teepol at less than 0·1 per cent, but emulsification does not appear until more than 1 per cent is present. There is an increasing amount of evidence that a surface-active substance will act as an emulsion breaker at low concentration and as a good emulsifier at some higher one. The distinction is perhaps similar to that between a good wetting agent and a good detergent. It is suggested that surface activity is not in itself sufficient for emulsification, nor is the lowness of the value of the interfacial tension related to the stability of the emulsion. In fact, it determines only the amount of work required to disperse the disperse phase. It is suggested that stability of an emulsion requires, in addition to lowering of interfacial tension, a mechanical barrier to coalescence of colliding drops. The mechanical barrier is provided by the lateral cohesion of the hydrophobic parts of the molecules in oil-in-water emulsions and, by extension, it must be assumed that it will be by adhesion of the non-hydrocarbon part of the molecules in water-in-oil, *e.g.*, by adhesion of –COOM groups, where M is a metal group in a soap. It is suggested further that the evidence shows that, at low concentrations, the charge due to the ionization of the emulsifier is not enough to give stability. It is not clear whether there is a threshold value of the mechanical barrier corresponding with a change of state of the adsorbed layer,

above which a substance can act as an emulsifier, or whether there is a gradual change beginning when the surface film is in the liquid condensed state and obeying the Amagat equation of state. It has been shown that a close-packed layer of sodium oleate is required for emulsion stability.[22, 23] It has been suggested that the failure of lower interfacial concentrations to give stability is due to displacement of the similarly charged ions when two drops approach.[24] The stabilizing ions will be pushed away from the point of contact. This cannot occur when the packing is already condensed. The magnitude of the viscous anomaly, however, is evidence in favour of the mechanical barrier postulated above. It will be noted that the only generalization about emulsions which has stood the test of experiment is that which states that the continuous phase will be the one in which the emulsifier has a bulk solubility. It is in this phase and between the parts of the emulsifier which are soluble in it that we are postulating attractive forces. It should be remembered, however, that the further condition of a concentration of emulsifying agent in this phase sufficient to form a certain minimum surface concentration of adsorbed emulsifier is, with these substances, similar to requiring that the solution in the bulk phase should be supersaturated. In this special case, the supersaturation is not a true one in so far as the excess above the true molecular solubility is aggregated to micelles. We do not know what is the distribution of a miscellar colloid between micelle and interface when a solution is shaken up with oil, and the matter is further complicated by internal solubilization of oil in the soap solution.[25, 26, 27] We therefore require to know the distribution of oil between micelles internally dissolving it and emulsified oil. At present, the extensive literature on emulsions is distinguished by an almost complete absence of critical quantitative enquiry. The greater part of the work published consists of observation upon systems in which the chemical nature of the emulsifying agent is in doubt or unknown.

The second idea of specificity is based on observed failures of demulsifiers to act on some emulsions after they have worked well upon others; and upon claims that some demulsifiers break a given emulsion "better" than others. The conclusion drawn that there is specificity between demulsifier and oil seems to go far beyond the evidence published. The conclusions of our work suggest that any wetting agent will break an emulsion of water-in-oil, provided that the amount used is such that the critical concentration of additive in the water present in the emulsion is attained and not exceeded by any large amount. This is a general and unambiguous denial of any specificity between additive and oil. It does not preclude the special difficult cases where, for example, solid powders are present and not wetted by the additive and not dissolved into the oil by moderate heating. In this case, however, any specificity would be between wetting agent and the adventitious solid contaminant; not the oil. It is suggested that all the so-called specificity effects attributed to the oil or the wetting-agent are, in fact, due to adventitious impurities. Failure to recognize the fundamental point of estimating the amount of additive needed as a percentage of the water present, instead of the usual practice of adding a percentage calculated on the total bulk regardless of its water content, must have led to great confusion, although this must have been offset by trial-and-error estimations of the amount required on samples taken from

each batch. Failure to recognize the importance of polyvalent cations must also have produced numerous otherwise inexplicable results.

It is not yet known to what effect specificity might arise to a limited extent from similarity or difference between the oil and the hydrocarbon part of the additive leading to a lower or higher interfacial tension. Nor is it known what is the minimum interfacial tension which will give the most rapid and complete breaking. Obviously, if it were reduced to zero, there is the condition for miscibility. If very small, sedimenting drops will be drawn out into filaments by the viscous resistance and re-emulsified. It is not therefore likely that small differences in interfacial activity would have much effect upon breaking efficiency. It should be recalled that the steps in demulsification of water in fuel oil emulsions are :—

1. Displacement of asphalt emulsifying layer from interface,
2. Re-solution of this in the oil, aided by moderate heating,
3. Coalescence of water droplets,
4. Sedimentation by drops.

Two and three are simultaneous and four overlaps them. Only in three does the actual value of the interfacial tension enter. Two may well be specific for an oil, but without any reference to the additive. There will be for any oil a minimum temperature at which the asphaltic bodies have gone into solution. This will depend upon the asphalt itself and also upon the efficiency of solvent power of the lighter fractions of the oil upon it, *e.g.*, aromatics will need less heating than aliphatics.

Before and during the war, the Germans used certain wetting agents for breaking crude-oil emulsions under names of Dismulgans for which specificity was claimed.[28] The testing methods used were not regarded by us as proof.[29] It was claimed that No. VII was the best for Pechelbronn (Alsace) and Reitbrook (Nr Hamburg) whilst VI was the best for Vienna. We found that samples taken from these three fields all broke equally well with Teepol.

ACKNOWLEDGEMENTS.

The material in this paper forms part of certain researches carried out for the Boiler Fuel Sub-Committee of the Admiralty Chemical Advisory Panel, Group II, and for Engineer-in-Chief, Admiralty. The work was carried out by one of the authors (A. S. C. L.) at the Imperial College of Science and Technology, London, to whom thanks are due for the use of a laboratory in the Department of Inorganic and Physical Chemistry, by the kindness of Professor H. V. Briscoe; at the Admiralty Fuel Experimental Station, Haslar, and at oil-fuel depots, and in H.M. ships. The authors wish to express their thanks and gratitude to the Officer-in-Charge, AFES, for his continued interest in the work and for valuable help and advice on all occasions. They are also indebted to many naval officers, and especially to members of the staff of Engineer-in-Chief, for unfailing help and kindness. Permission to publish this work is acknowledged.

APPENDIX I.

Fig. 16 shows the AFES apparatus for measuring the water content of an oil. (B.P. Appl. 7242/46.)

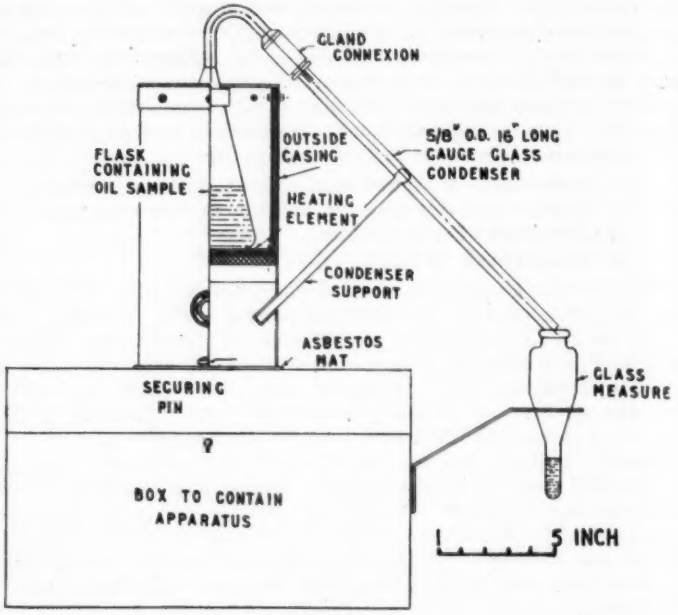


FIG. 16.

WATER DETERMINING APPARATUS FOR USE AT SEA.

This apparatus, which is a modification of the Dean and Stark method, was designed for use in H.M. ships at sea. It is made of metal with the exception of the glass measuring vessel, which is of the conventional form, and the condenser for which a boiler gauge glass is used. This was chosen because ships carry spares. The determination of the water differs from the Dean and Stark method in one important respect, namely, that the volatile spirit is not refluxed, but is all distilled over into the receiving bulb. This has the advantage that a separate recovery of the spirit is not required, the bulk of the spirit in the receiver being poured back into the spirit container, where it is maintained dry by a little calcium chloride. At the end of a run, the residue in the flask is poured out while still warm. No cleaning is necessary as all the water has been removed already by distillation. The heating is controlled by a two-way switch giving full power for heating up and a small current as soon as distillation commences. The apparatus, with spare receivers, is packed in a box which, as shown in the diagram acts as support for it during use. If the box is fixed securely, determinations can be made when there is considerable motion of the ship.

This apparatus has been used at sea with complete satisfaction. Analyses can be made more rapidly with this apparatus than with the conventional glass one, because time is not lost waiting for it to cool at the end of each run.

APPENDIX II.

Fig. 17 shows the AFES "thief." It was constructed with the object of sampling at depth accurately and with certainty. The usual jerking of a

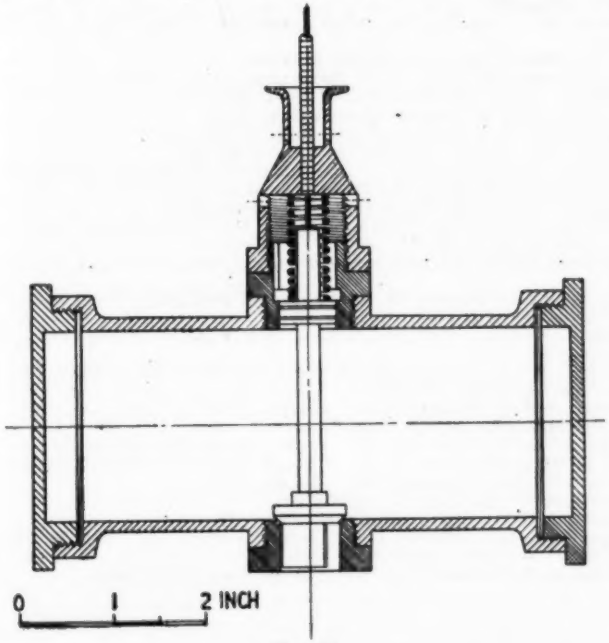


FIG. 17.
A.F.E.S. "THIEF."

rope to admit the sample was inadmissible, and the valve was operated by a Bowden cable, which was also the support for the vessel. The sample was removed from the pot by unscrewing one cap. This pot was most satisfactory in performance and is very much cleaner to use than conventional types which, being larger, carry up much more oil on the outside. The Bowden cable passed through a wiper fixed in a brass bar which was laid across the manhole of the tank to be sampled. This bar also acted as a zero line for calibrating the depth. It has the defect that a considerable length of cable has to be kept from kinking, but in later models it is proposed to wind this around a drum. For different sizes of tank, different lengths of cable are available and these are interchangeable, using a simple mechanical union to the pot. This is not shown in the diagram. Use of this

pot suggested as a further improvement that the caps should be attached by hinge and closed by a spring clip to avoid loss of a cap by dropping it into the tank when unscrewing it with hands covered with fuel oil. The pot is easily cleaned both inside and out.

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AVIATION FUELS: THE DEVELOPMENT OF TESTS FOR DETERMINING RICH-MIXTURE PERFORMANCE.

By D. A. Howes (Fellow) and R. Stansfield (Fellow).

Introduction.

The technology of aviation-fuel manufacture has undergone changes of considerable importance during the past eight years, and the production of 100 O.N. fuels in particular, which was very small in 1939, had reached enormous proportions in 1945.

This development, which was accelerated by the extreme urgency of war, necessitated the preparation of improved engine-test methods for determining anti-knock ratings in available designs of laboratory engine, and also required research on the anti-knock values of hydrocarbons of various types under the new conditions of test.

This paper records for the first time work carried out at the Research Laboratories of the Anglo-Iranian Oil Company Ltd., at Sunbury-on-Thames, England, during the early part of the war; the work helped both to develop satisfactory test procedures and to evaluate the anti-knock properties of fuels for use in aero-engines. A description is also included of the C.R.C. F–4 Method of Test which is now in wide use, together with a discussion of the rating scales used.

The CFR Rich-Mixture Test.

Prior to the outbreak of war in 1939 it was known that the laboratory methods of rating aviation fuels in use at that time were unsatisfactory as a guide to performance in full-scale engines under conditions of rich-mixture operation as used for take-off, climb, and all-out level flight, although it was considered that use could be made of the CFR engine to determine suitability for cruising, *i.e.*, weak mixture, operation.

When aviation fuels were still in the range limited at the upper end to about 79 O.N., a series of tests made for an Institute of Petroleum committee under the guidance of the British Air Ministry indicated that the knock ratings obtained in full-scale engines could be measured relatively on the octane-number scale by using the CFR engine to Motor Method conditions, except that the mixture was maintained at 260° F instead of the standard temperature of 300° F.

As fuels of higher O.N. came into use, it was found desirable to raise the mixture temperature for these to the Motor Method standard value.[1]

This was soon found not entirely to guarantee the quality of supplies, and it became necessary for laboratories first to make the Motor Method test and then, if the fuel met the specified O.N., to submit a relatively

large sample to an approved engine-builder's laboratory or, in certain circumstances, to the Royal Aircraft Establishment, for further tests in full-scale single-cylinder engines under conditions approximating to take-off. In such tests, supercharge was applied and mixtures used which were considerably richer than the almost chemically correct ones required by the Motor Method.

This complication of test method arose because it was found that fuels of equal knock rating under cruising conditions might differ considerably in knock limit when running supercharged and at the rich mixtures used for take-off, and it had become necessary for an aviation fuel to have a good " rich-mixture " rating, particularly for military purposes, to ensure that a bomber or transport aircraft would take off with maximum possible load, and that fighter aircraft should have a tactical advantage in rate of climb and performance during pursuit, combat, and evasive action.

An early attempt to develop a laboratory test for supercharged aero-engine fuel behaviour was described by Boerlage, Peletier, and Tops in 1935,[2] but the details were unsuitable for the engines used during the War running on fuels of 87 and 100 O.N.

It seems probable that this work was directed to fuels intended mainly for American designs of aero-engine, but U.S. technical opinion was, not unnaturally, slow to admit the relative importance of rich-mixture behaviour until driven to do so by the pressure of military necessity.

For some time all high-octane fuels developed at the Anglo-Iranian Oil Company's Research Laboratory at Sunbury were tested by the Motor Method and then examined for take-off behaviour in a Pegasus single-cylinder engine by the Bristol Aeroplane Company, or by the R.A.E. at Farnborough.

Results were so disappointing in one or two cases of fuels relatively good according to Motor Method ratings that it became imperative to start without delay a thorough investigation into the relation between fuel type and rich-mixture behaviour. A Pegasus engine was ordered and a suitable special building designed to house it, and early in 1939 it was also decided to attempt to use the CFR engine, at least as a temporary measure, as a rich-mixture test unit.

An account of the technique developed on this engine was published in the summer of 1939.[3] Most previous work had been influenced by the assumption that lack of correlation between laboratory and full-scale ratings was due to the great dissimilarities in size, running speed, type of cooling, etc. which existed between the CFR and air-cooled aero-engines. Attempts to bridge these differences had been centred round the use of high jacket temperatures, with increased engine speeds and even supercharge, but usually still with mixture conditions approximating to chemically correct, and often with instrumentation depending on measurement of a local temperature in the cylinder head.

After full consideration of the problem it was concluded that mixture strength might well be the most important of any single variable, and this was the one which had previously been almost entirely neglected.

The CFR method developed at Sunbury during the early part of 1939 was based on the fact that a satisfactory aviation fuel must have a certain minimum anti-knock value both under lean-mixture cruising and rich-mix-

ture take off conditions, although the two minima might not be identical in terms of appropriate reference fuel blends.

It had been shown previously that mixture strength had a pronounced effect on the degree of knock, and that maximum knock occurred at about the chemically correct mixture.[4] The CFR MM. rates fuels at maximum knock mixture strength, and therefore is of no value as a test for rich-mixture conditions.

The Sunbury rich-mixture test made use of a standard CFR engine, but the procedure differed from the Motor Method in several respects, the most important being that ratings of anti-knock value were determined at various mixture strengths from theoretically correct to as much as 50 per cent rich. Other changes in technique and equipment included the use of a C.A.V. fuel pump instead of a carburettor to improve precision of mixture control; removal of the diaphragm plate in the manifold to increase volumetric efficiency; the addition of an inlet air heater; and alteration of the ignition advance.

The conditions finally selected which gave a good approximation to aero-engine rich-mixture performance were :—

Speed . . .	900 r.p.m.
Ignition advance .	19° before t.d.c.
Inlet air temperature .	150° F.
Mixture heater . .	Constant watts at a value giving 300° F on the reference fuels.
Jacket temperature .	212° F.

Shrouded inlet valve.
Fuel injection into manifold starting 45° after t.d.c. on suction stroke.

A cathode-ray engine indicator was used for detecting and standardizing knock, an electro-magnetic pick-up unit being fitted into the hole normally used for the bouncing-pin, and the rate-of-change of pressure, or dp/dt diagram, was observed.

Standard CFR reference fuels were used from which blends could be made to bracket or match the samples for knock intensity, and results were expressed in O.N. to an arbitrary calibration based on Motor Method ratings.

The preferred rating was that taken with the mixture strength corresponding to a fuel flow 45 per cent richer by volume than the chemically correct flow for the reference fuels.

Correlation between this test and rich-mixture ratings obtained on the Bristol Pegasus engine was extremely good for most fuels, rarely differing from a mean line by as much as 2 O.N., although results from alkylate blends required a correction up to twice this amount.

It was soon found that there were well-defined differences between fuels of different chemical compositions in regard to change in anti-knock value with change of mixture strength. This is shown in Fig. 1, in which are given results of typical 100 O.N. aviation fuels of the 1939 type.

From early in 1939 until the end of that year, the test was used in the A.I.O.C. laboratories both for research purposes and for the preliminary grading of blends sent away for tests in full-scale cylinders. It was also satisfactory for control testing in the refineries and was used for that purpose for a considerable period until a reliable laboratory supercharged method had been developed.

The CFR rich-mixture test led to new ideas regarding the most desirable chemical compositions for aviation fuels for use in highly supercharged engines under take-off conditions, and confirmed that blends of predominantly paraffinic or *iso*paraffinic nature were not satisfactory. It seemed, furthermore, that the aromatic hydrocarbons, and to a less extent the naphthene hydrocarbons, were essential for good rich-mixture behaviour, while the *iso*paraffins such as *iso*octane, hydrocodimer, and the alkylates were of the greater value at weak mixtures as used for cruising. Binary blends of these synthetic paraffins and straight-run petroleum distillates of low aromatic and naphtene content were deficient in rich-mixture performance; on the other hand, there was a definite relation between aromatic content and rich-mixture rating, the higher the aromatic content the better the performance.

Analysis of the results of various tests of several blending components made it apparent that a well-balanced fuel for aviation purposes, par-

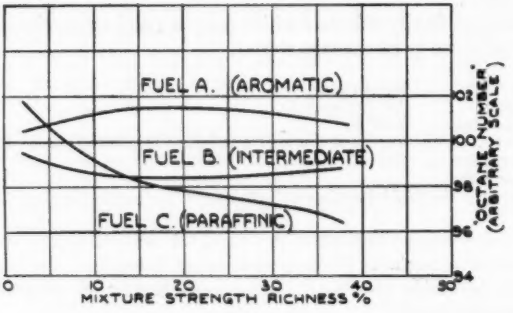

FIG. 1.

TYPICAL RESULTS ON 100 O.N. FUELS CFR RICH-MIXTURE TEST.

ticularly a 100-octane fuel, giving good performance both under weak- and rich-mixture conditions should include (*a*) *iso*paraffins such as *iso*octane, alkylate, etc., to give it a good CFR MM. O.N. which guaranteed adequate weak-mixture behaviour, and (*b*) aromatics to give the requisite rich-mixture quality. It was also appreciated that these two essential constituents should be blended with the maximum possible amount of high-grade straight-run petroleum distillate consistent with specification requirements in order to economize in their use. This was very important in the earlier stages of the war when both *iso*paraffins and aromatics were in short supply.

It thus came about that the 100 O.N. aviation fuels used by the Allies during the recent war became essentially three component blends, and they remained such until the War ended in 1945. The *iso*paraffinic material employed in 1939 and early 1940 was largely *iso*paraffin and hydrocodimer, made respectively by polymerization of *iso*butene and copolymerization of *iso*butene and normal butenes followed by saturation hydrogenation. The alkylation process, discovered in the A.I.O.C. laboratories early in 1938 [5] allowed a greater yield of *iso*paraffinic product to be obtained from a given amount of *iso*butene and normal butenes; it was rapidly installed on the

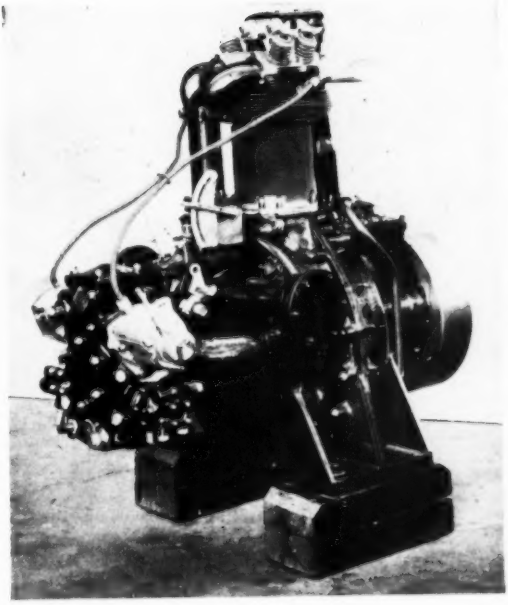

FIG. 2.

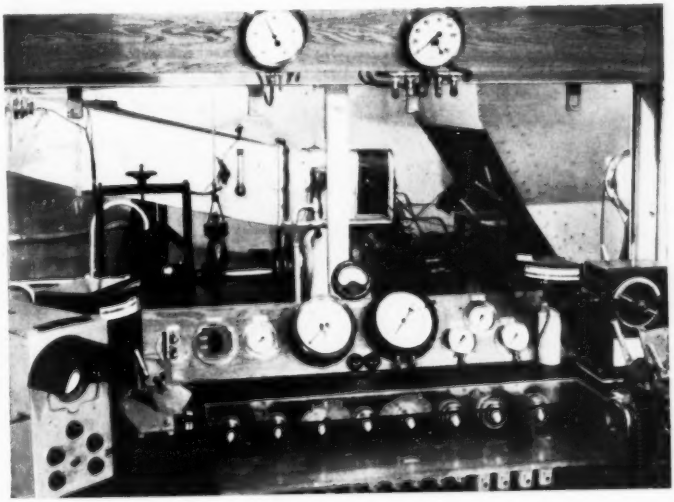

FIG. 3.

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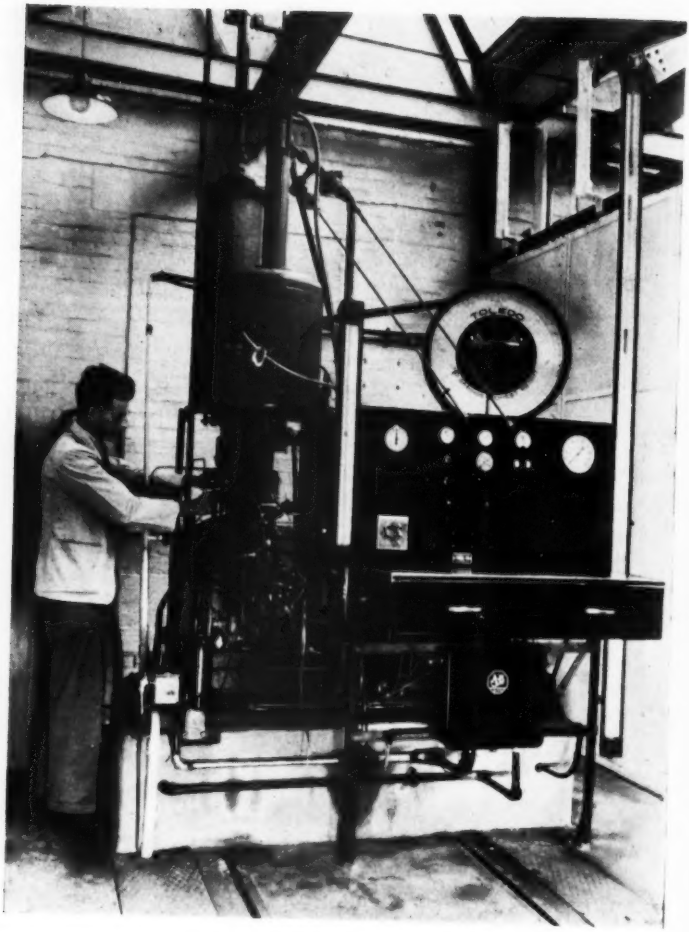

FIG. 10.

CFR–F 4 TEST ENGINE.

commercial scale and was soon responsible for the major part of the synthetic *iso*paraffin produced. Another *iso*paraffin used in large quantities was *iso*pentane, obtained by fractional distillation of natural petroleum. The quantity blended into aviation fuels was, however, limited because of vapour-pressure considerations. Synthetic *neo*hexane and di*iso*propyl were also employed. The aromatic hydrocarbons used were obtained in various ways of which, in America, the most important was catalytic cracking; a process which can be adjusted, by operating under severe conditions, to give a light distillate of aviation-spirit boiling range which is very rich in aromatic hydrocarbons. In addition solvent-extraction processes were employed to extract benzene, toluene, xylenes, and ethyl benzene from straight-run petroleum distillates, and cracking and pyrolysis processes were used to some extent. Furthermore, specific aromatic hydrocarbons of particularly good rich-mixture properties were specially synthesized; for example cumene (*iso*propyl benzene) and tertiary butyl benzene.

The straight-run petroleum distillates employed in war-time aviation fuels were necessarily of high O.N., otherwise the quantity which could be incorporated in the finished blended fuels was very low, and high contents of relatively expensive and short-supply aromatics and *iso*paraffins became necessary. The availability of high O.N. light-petroleum distillates was, however, limited, and in the particular case of Iranian crude oil, which yields straight-run distillates of low O.N., it was necessary to submit these distillates to a series of highly efficient fractional distillations in order to eliminate from them the normal paraffin hydrocarbons, pentane and hexane. In this way high O.N. fractions, consisting predominantly of *iso*hexanes and *iso*heptanes with the naphthenes in the same boiling range, were produced commercially on a considerable scale at Abadan, the combined production being no less than 315,000 g.p.d.[6] Average properties of these fractions were as follows :—

	*iso*Hexane.	*iso*Heptane.
Sp. gr, @ 60° F	0·6670	0·7290
I.B.P., ° C	57·5	81·5
50% distilling to	59° C	85°·C
F.B.P., ° C	62	101
Aromatics, % vol	0·3	4·7
Aniline point, ° C	68·7	51·1
O.N., CFR motor	79·5	74·3
O.N. + 5·5 ml T.E.L./I.g.	103	91·9
F_4 (3-C) rich-mixture rating index no., 4·8 ml T.E.L/I.g.	109·4	111·5
F_4 (3-C) rich-mixture rating index no., 5·5 ml T.E.L/I.g.	112·6	116

Chemical Composition % wt.

n-Pentane	3·0	*n*-Hexane	4·0
*cyclo*Pentane	8·4	Methyl*cyclo*pentane	12·1
*neo*Hexane	4·2	*cyclo*Hexane	17·9
Di*iso*propyl	13·1	Dimethyl*cyclo*pentanes	16·9
2 : 3-Methylpentanes	71·0	Methyl*cyclo*hexane	0·2
n-Hexane	0·3	Benzene	4·7
		Toluene	Trace
	100·0	2 : 2- and 2 : 4-Dimethylpentanes	4·7
		*iso*Heptanes (85–95° C)	39·1
		n-Heptane	0·4
			100·0

As a typical example of the components which were used in the commercial manufacture of 100 O.N. aviation fuel, the following materials, all produced in the A.I.O.C. refinery at Abadan, Iran, may be quoted :—

Iso*paraffins*.—*Iso*Pentane, *iso*hexane, *iso*heptane, *iso*octane hydrocodimer, alkylates from C_4 and C_5 olefins, hydrogenated polymers of propylene and butene.

Aromatics.—Benzene, toluene, xylene, and ethyl benzene obtained by solvent extraction with liquid sulphur dioxide; Benzene–toluene mixture obtained by the pyrolysis of propane–butane mixtures.

Aromatics.—Cumene—produced by the condensation of benzene and ethylene.

The Pegasus Single-Cylinder Aviation Fuel Test Unit.

The CFR rich-mixture test described above played a very important part in the development of 100 O.N. aviation fuels in the early part of the war, and was of particular value in showing the relative merits of *iso*-paraffins and aromatics and in focusing attention in the petroleum laboratories on rich-mixture behaviour. It was not, however, regarded as an ideal test, partly because of minor deviations from correlation with important full-scale engines, and partly because it could not be extended to higher O.N. fuels without the use of a blending procedure or extrapolation of uncertain validity.

Steps were taken, towards the end of 1938, to provide a special building for aviation-fuel testing at the Sunbury Research Laboratories of the A.I.O.C., and a single-cylinder Bristol Pegasus engine was selected as the most suitable test unit. The building and equipment were not ready for use until October 1939, and then only for testing fuels in the 87 O.N. range, the special high-compression piston used for 100-octane fuel not being fitted until early in 1940.

At the time of its completion this installation was probably unique among single-cylinder test units in respect of the thorough nature of the vibration and sound insulation provided. The engine, coupled to a water dynamometer and, through a clutch, to a starter motor which also served to drive a cooling-air fan, was mounted with its accessory equipment on a massive concrete block resting on cork. This bed was enclosed in a brick-built cubicle, the walls of which rested on rubber slabs; the walls were covered with an acoustic treatment to deaden echo, and the large inspection window through which the engine could be seen from the outer control room was made of two separated panes of toughened glass each $\frac{7}{8}$-inch thick. The cubicle doors were constructed specially to give good sound insulation, and the control room was acoustically treated, and contained a bench fitted with necessary instruments and engine controls which were duplicated on the engine itself. A supercharger with electric-motor drive was installed in the cubicle, with remote controls to permit of regulation of supercharge from the control bench (Figs. 2 and 3).

The equipment proved very satisfactory, both mechanically and as regards reproducibility of results over long periods, and nearly two thousand complete performance curves were determined on it until it was superseded

late in 1942 by a Bristol Hercules sleeve-valve unit installed in a similar type of building.

The making of a fuel test depended on the accuracy with which a detonation level of relatively low intensity compared with general engine noise could be reproduced from one observation to another, and the only satisfactory available method for estimating this intensity was by ear. An expert operator could work inside the engine-test cubicle and distinguish detonation from the general and very high noise level, but it was difficult to do this for more than two or three hours in a day without severe strain. The special construction of the Sunbury building made testing very much more accurate and less arduous, for it was found that the detonation could be readily observed and standardized from the control bench outside the cubicle, provided the door was left slightly open, the acoustic treatment acting as a preferential sound absorber for the low frequencies emitted by the engine without reducing the high-frequency detonation sound to a marked extent. It was thus possible for operators to work with high accuracy, and for tests to be continued for periods up to eight or nine hours a day when necessary.

Means were provided for electric heating of the inlet air to the engine, with automatic regulation of temperature, and also for filtering and cooling the lub. oil during a test. The dynamometer was fitted with a hydraulic method of torque balancing and a remote-reading load indicator was situated in the control room; all adjustments, including those of the dynamometer water sluices, were made from the control bench. Results were plotted as each test proceeded so that it was possible, when desired, to prepare a new experimental blend within a few minutes of completing the previous test.

The test conditions employed for 100-octane fuels were :—

Compression ratio	8 : 1
Speed	2400 r.p.m.
Cylinder-head temperature	185° C.
Inlet air temperature	110° C.
Ignition advance	29° b.t.d.c.
Oil inlet temperature	70° C.

The engine was run from about normally aspirated conditions upwards to a maximum supercharge depending on the fuel sample, the mixture strength being adjusted for each supercharge level so that the detonation was maintained at the standard level described above.

Fuel consumption and b.h.p. or b.m.e.p. readings were taken at each supercharge interval of about 1½ p.s.i., and particular care was taken to secure accuracy at the maximum obtainable b.m.e.p., and also to carry the test a little beyond this maximum.

A complete test took a little more than half an hour to make—quicker testing led to inaccuracies.

During each test a curve was drawn connecting b.m.e.p. or performance with specific fuel consumption. This curve, referred to as the " mixture-response " curve, defines the response of detonation-limited power output to mixture strength. A typical example is reproduced in Fig. 4. The maximum power output reached at rich mixture is referred to as the " peak performance," and the term " rich-mixture performance " on this engine

refers to the position and the shape of the upper part of the curve from about 0·6 lb/b.h.p.hr. specific fuel consumption up to or just beyond the peak value.

The Pegasus engine test and the above test conditions were specified in official British aviation-fuel specifications from 1939 up to 1942, and all 100 O.N. aviation supplies were required to give a performance curve at least equal to that of a 100 O.N. reference fuel which was known to be satisfactory in full-scale engines and of which large supplies were set aside for test purposes.

For various reasons the reporting of results in the form of b.m.e.p. values was abandoned, and rich-mixture ratings were given in terms of a

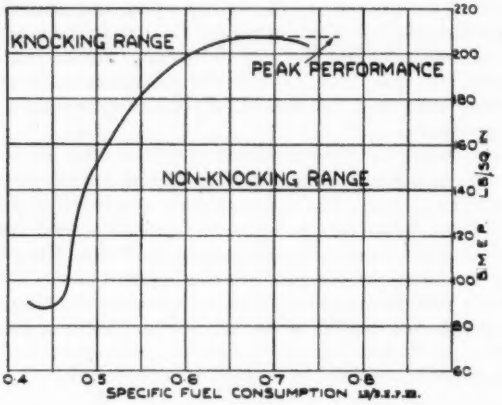

FIG. 4.

TYPICAL AVIATION FUEL PERFORMANCE CURVE IN THE PEGASUS SINGLE-CYLINDER ENGINE.

relative performance number expressed as the ratio between the peak performance of the sample and that of the standard reference fuel. This relative-performance scale was used for some time in communications with the U.S. regarding aviation-fuel quality when test results were quoted; it was convertible to b.m.e.p. values if the performance values were multiplied by 2·10, but the mean-pressure figures had no practical significance except in relation to the Pegasus engine run strictly to the specified test conditions and using the high-compression-ratio piston designed solely for fuel-testing purposes.

Fig. 5 gives results of Pegasus engine tests on a range of 100 O.N. fuels of different chemical compositions and the standard reference fuel is included for comparison.

The Pegasus unit used according to the procedure described for determining ratings in terms of " relative peak performance " values proved to be a very convenient method for assessing the anti-knock merits of aviation fuels for rich-mixture behaviour, and provided a means for the critical study of the worth of many possible components. Thus, by making up a

series of binary blends of a single aviation component in a suitable low-performance base stock it was found that, for most components, the relation between relative peak performance and composition was sufficiently linear for the extrapolation to 100 per cent concentration of the particular component to give a close approximation to the performance of the undiluted component. The extrapolated value so obtained was termed the Pegasus blending number, in order to differentiate from the actual performance of the undiluted component.

It was found that, within reasonable limits of error, the relative peak

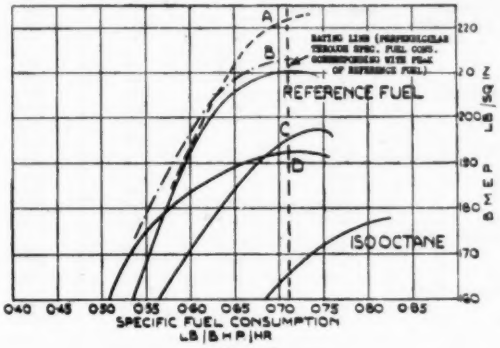

FIG. 5.

PEGASUS PERFORMANCE CURVES OR FUELS OF 100 CFR. MM. O.N.

Fuel A =	50% hydrocodimer. 26% pyrolysis benzole 15% *iso*pentane 9% straight-run gasoline	+ 4 ml T.E.L/I.G.
Fuel B =	54% hydrocodimer 27% pyrolysis benzole 19% straight-run gasoline	+ 4 ml T.E.L/I.G.
Fuel C =	48% *iso*octane 5% *iso*pentane 47% naphthenic gasoline	+ 4 ml T.E.L/I.G.
Fuel D =	74% alkylate 26% paraffinic gasoline	+ 4 ml T.E.L/I.G.

performance of a multi-component blend could be calculated arithmetically from the volume percentage composition and the Pegasus blending numbers of the components. Thus, if the components A, B, C, and D of a four-component blend have blending numbers of a, b, c, d and are present in concentrations of a', b', c', and d' volume percentage respectively, then the relative performance of the blend is given by the expression

$$\frac{aa' + bb' + cc' + dd'}{100}.$$

Similarly, the Pegasus blending number of an unknown component may be calculated by the expression

$$\frac{100(y - x)}{z} + x$$

TABLE I.

Component.	Purity, %.	O.N. (CFR.MM.).		Pegasus Blending No.	
		Neat.	+4·0 ml T.E.L/I.G.	+4·0 ml T.E.L/I.G.	+4·8 ml T.E.L/I.G.
Abadan C_4 alkylate	—	92	—	114	118
" " "	—	94	—	120	124
" Hydrocodimer	—	94	—	130	134
" *iso*octane	—	98·5	—	120	124
" C_3/C_4 hydropolymer	—	75	93·5	69	75
" *iso*pentane	90 *iso* C_5	89	—	103	108
" *iso*hexane cut	—	79	99	82	85
" *iso*heptane cut	—	73·5	89	91	95
" aromatic extract	70 aromatics	84	91·5	117 *	125 *
" straight run gasoline	—	70	88	55	57
" " " benzine	—	60	79	43	45
*neo*Hexane	90	93·5	—	100	—
Di*iso*propyl	97	94·5	—	122	—
2 : 2 : 4-Trimethylpentane	100	100·0	—	117	—
Normal hexane	95	28	65	−40	—
Benzene	99·5	—	—	145 *	—
Toluene	98	—	—	164 *	—
Xylenes (mixed isomers)	100	—	—	142 *	—
Ethylbenzene	99+	—	—	162 *	—
*iso*Propylbenzene	100	—	—	192 *	—
tert-Butylbenzene	100	—	—	198 *	—
*cyclo*Pentane	100	84·2	94·4	250 *	—
Methyl*cyclo*pentane	99+	79·4	90·4	132 *	—
Dimethyl*cyclo*pentanes (mixed isomers)	95+	77·6	90·8	88 *	—
*cyclo*Hexane	98	77·0	87·5	145	—
Methyl*cyclo*hexane	95+	72·3	84·0	88	—
Dimethyl*cyclo*hexanes (mixed isomers)	97	66·7	79·4	42	—
Ethyl*cyclo*hexane	97	43·4	—	−19	—

* 20% Concentration.

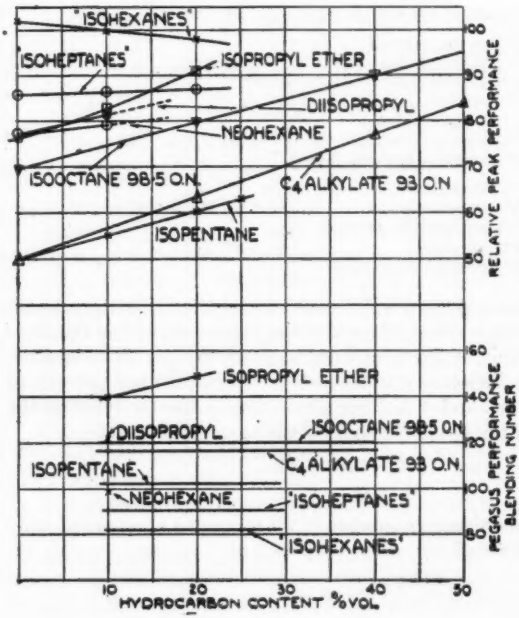

FIG. 6.

RICH-MIXTURE BEHAVIOUR OF PARAFFIN HYDROCARBONS (AND ISOPROPYL ETHER) IN PEGASUS SINGLE-CYLINDER.

(All blends contain 4·0 ml T.E.L/I.G.)

where x = Relative performance of base spirit and y = Relative performance of base spirit blended with z per cent of the component under test.

It is thus evident that Pegasus blending numbers are very similar to the blending O.Nos which have been widely used in the interpretation and assessment of CFR. knock-rating data. As with blending O.Nos, Pegasus blending numbers are not entirely independent of concentration, but in most cases the effect is not marked. In some cases, however, the relationship between Pegasus blending number and concentration deviates markedly from

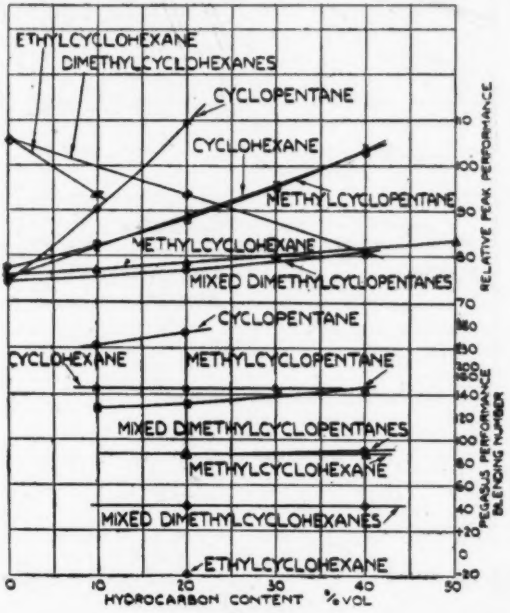

FIG. 7.

RICH-MIXTURE BEHAVIOUR OF NAPHTHENE HYDROCARBONS IN PEGASUS SINGLE-CYLINDER AERO-ENGINE.

(All blends contain 4·0 ml T.E.L/I.G.)

the linear, and it is necessary then to quote the concentration at which the Pegasus blending number is determined.

Typical values of the Pegasus blending number of aviation-fuel components and a selection of hydrocarbons in the aviation-fuel boiling range are given in Table I.

It will be observed that the blending number is dependent on T.E.L. concentration. Furthermore, the effect of hydrocarbon composition on Pegasus rich-mixture performance is similar to that found for the CFR. rich-mixture test, the aromatic hydrocarbons as a class being particularly effective in this respect. This is illustrated in Figs. 6, 7, and 8 which give the results of tests of binary blends of pure hydrocarbons in various base spirits.

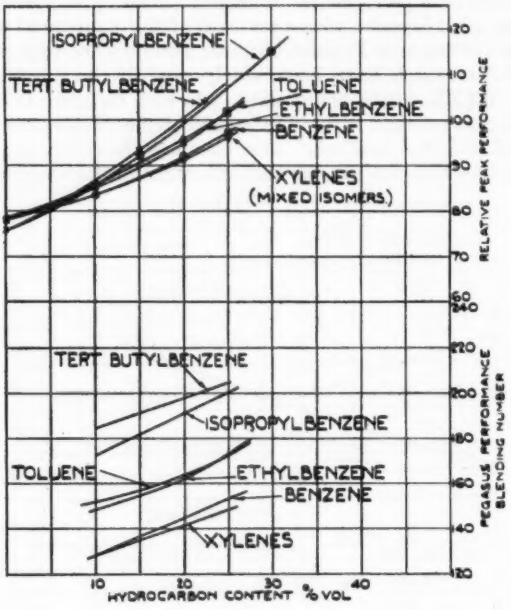

FIG. 8.

RICH-MIXTURE BEHAVIOUR OF AROMATIC HYDROCARBONS IN PEGASUS SINGLE-CYLINDER AERO-ENGINE.

(All blends contain 4·0 ml T.E.L/I.G.).

THE EFFECT OF SULPHUR CONTENT ON THE PEGASUS PERFORMANCE OF AVIATION FUELS.

It is well known that the presence of certain types of sulphur compounds has an adverse effect on the O.N. and lead response of motor gasolines. The sulphur compounds which exhibit the most marked effect are the polysulphides, disulphides, and mercaptans. In 1940, however, there was no information concerning the effect of sulphur bodies on rich-mixture performance of an aviation fuel, and it was considered necessary to examine this point.

It was found that the rich-mixture performance of an aviation fuel is much more sensitive to the presence of sulphur compounds than the CFR. O.N., the particularly deleterious classes being the same as those mentioned above. On the other hand, thiophene has practically no effect on rich-mixture performance. Fig. 9 is typical of the results obtained in this investigation.

Thus in Fig. 9 the Pegasus performance of a 90·6 O.N. aviation fuel containing 3·5 ml T.E.L/I.G. with a sulphur content of 0·014 per cent wt, increased from *ca* 72 to *ca* 89 (approximately 20 per cent) when the sulphur

content was reduced to 0·0002 per cent, whilst the O.N. increased to 93·6. Similarly, in the case of a fuel containing 4 ml T.E.L/I.G. decreasing the sulphur content from 0·007 to 0·0006 per cent increased the leaded O.N. from 97·6 to 99·3 whilst the Pegasus performance rose from 98·5 to 105.

It is thus necessary to desulphurize almost completely the components

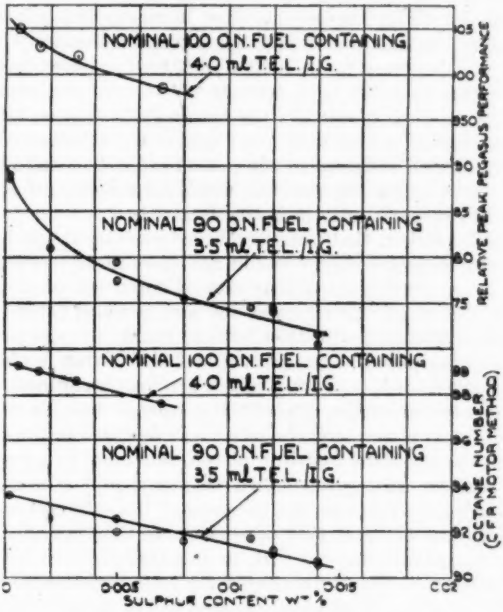
NOMINAL 100 O.N. FUEL CONTAINING 4·0 ml T.E.L./I.G.
NOMINAL 90 O.N. FUEL CONTAINING 3·5 ml T.E.L./I.G.
NOMINAL 100 O.N. FUEL CONTAINING 4·0 ml T.E.L./I.G.
NOMINAL 90 O.N. FUEL CONTAINING 3·5 ml T.E.L./I.G.
RELATIVE PEAK PEGASUS PERFORMANCE
OCTANE NUMBER (C.F.R. MOTOR METHOD)
SULPHUR CONTENT WT. %
0
0·005
0·01
0·015
0·02

FIG. 9.

THE EFFECT OF SULPHUR ON THE PEGASUS PERFORMANCE AND LEADED O.N. OF AVIATION FUELS.

of an aviation fuel in order that the finished fuel shall not be wasteful in the use of the higher performance components. This was done at the Abadan refinery by conventional methods, but difficulties were found in accurately measuring the residual sulphur content of the refined components. As a subsidiary investigation to the main aviation-fuel programme, a method for the determination of sulphur contents down to 0·0001 per cent was therefore developed by the Anglo-Iranian Research laboratories.[7]

DEVELOPMENT OF THE SUPERCHARGED RICH-MIXTURE TEST ON THE CFR ENGINE.

Useful as the CFR rich-mixture test had been during the early stages of development of 87- and 100-octane aviation fuels from Iranian crude, it was appreciated that a laboratory method of wider scope and greater accuracy was required.

The Pegasus engine needed a sample of about 8 gal, and this quantity put a severe strain on laboratory resources when some materials, such as pure hydrocarbons, were being examined. Furthermore, the comparatively extensive and costly installation involved imposed a severe limit on the number of such test units that could be laid down.

It was decided, therefore, to make further efforts to modify one of the existing Sunbury CFR. engines so that accurate rich-mixture ratings could be obtained on this unit with samples of not more than 1 gal.

This work was begun early in 1940, and it was assumed from the start that if the engine could be so operated that it gave performance curves similar in slope to those obtained from the Pegasus engine, and if two or three extreme fuel types such as pure *iso*octane, *iso*octane plus T.E.L., and *iso*octane blended with say 40 per cent of aromatics could be placed in the proper relative order, the problem would be solved and all remaining fuel types would automatically be correctly rated.

It was already obvious that unsupercharged running at any speed within the range of the standard engine would not meet these requirements, and steps were taken to modify the unit in several important particulars.

The cast-iron flywheel was removed and a steel wheel fitted to permit of higher rotational speeds up to 2400 to 2600 r.p.m. if necessary, with the object of increasing piston temperatures and also giving a wider range of control of the reaction time during which pro-knock compounds could be formed in the pre-combustion period; the balance weights were reduced to suit an aluminum piston, and the latter was designed to the same overall dimensions as the standard cast-iron piston, but more in accordance with aero-engine practice as regards crown thickness and metal distribution between the gudgeon pin bosses and the crown; the split cast-iron cylinder-clamping sleeve was replaced by a solid sleeve of much greater mechanical strength, the design allowing the C.R. to be adjusted when the engine was serviced, if necessary, but not arranged for ratio adjustment during running; a supercharger was provided capable of giving an inlet pressure up to 2 atm abs, and air-flow measuring equipment, air heaters, and an inlet-air-surge chamber were fitted; the fuel supply was controlled by a C.A.V. pump similar to the one used for the previous rich-mixture test and the engine was coupled to a cradled dynamometer so that accurate measurements of power could be made. It was not possible at the time to obtain a high-lift camshaft to give the necessary increase in " breathing " capacity, but this difficulty was overcome by altering the valve gear so that unequal rocker arms increased the lift to 50 per cent above that given by equal arms. The push rods were controlled for return by separate springs independently of the two springs used on each valve. The exhaust valve was sodium cooled and fabricated from scrap valves from the Pegasus engine.

Provision was made for ethylene-glycol cooling by the addition of an oversize condenser, and the exhaust system included a suitable expansion chamber and a silencer of liberal dimensions.

Apart from a small adjustment to piston clearance, the modified engine ran without any mechanical trouble from the start, and with notable freedom from noise. This was due to the characteristics of the new valve springs and, in the authors' opinion, the use of similar springs would be a

welcome improvement to the standard CFR 3–C engine, which is fitted with stiff springs giving much too high a seating pressure and resulting in valve-gear noise which ought not to be tolerated for detonation testing.

The first runs were made very soon after the Ministry of Aircraft Production had asked the various British oil-industry laboratories and the R.A.E. at Farnborough to undertake the development of a supercharged CFR unit. They consisted of performance-curve determinations on each of the fuels referred to above, beginning with a relatively low engine speed and the ignition set for optimum power.

Study of curves taken at each of a few speed and ignition settings showed the probable direction in which changes should be made to bring the results into closer agreement with Pegasus curves, and in a relatively short time it was concluded that high speed, high jacket temperature, well-advanced ignition, and high inlet-air temperature were all necessary. At this stage a cathode-ray indicator was applied to determine the behaviour of the inlet and exhaust systems in respect of volumetric efficiency, and modifications were made to increase this to the maximum without resort to special cams or other items not readily obtainable at the time.

Five reports on the progress of the work were issued between the end of October 1940 and the end of March 1941, and these were circulated to the other British laboratories working on the problem, and also to the U.S.A.

The last of these reports recorded that good correlation had been obtained with Pegasus peak ratings on a wide range of fuel types, and the selected running conditions were :—

Compression ratio	7·25 : 1
Speed	2100 r.p.m.
Jacket temperature	150° C.
Inlet air temperature	150° C.
Ignition advance	35° b.t.d.c.

Rich-mixture ratings were determined on a b.m.e.p. basis.

Other laboratories reported results obtained on somewhat similar modifications of the CFR engine at intervals between March 1941 and March 1942, and by this time ratings of 100 O.N. fuels from the Hercules sleeve-valve engine were available, and correlation was centred round this full-scale cylinder instead of the earlier Pegasus type.

Towards the close of the co-operative period of the research, steps were being taken to standardize a method based on the most suitable features of the several possible solutions, but before this proposal was implemented it was obvious that the CFR 3–C test, which was approaching finality in the U.S., should be almost equally acceptable for ratings for British full-scale engines. The use of a common method by the two countries had too many advantages during the war to justify different procedures, even though the American test might not be quite as suitable for British engines as the one which it was decided to abandon.

The 3–C test, now known as A.S.T.M. Designation D909–47T uses a CFR engine of the high-speed or low-speed crackcase type fitted with a variable-compression cylinder held in a redesigned sleeve of sufficient strength to withstand supercharged working conditions. The C.R. is adjusted to 7 : 1 and kept at that value for all tests. The high-duty magneto is set to an ignition advance of 45° before t.d.c. Arrangements

are made for supercharging, and the inlet air is passed through two surge chambers, with a metering orifice between, and then through a further chamber containing an electric-heating element before it reaches the inlet manifold into which the fuel is sprayed from a spray valve fed by a fuel pump. The connecting rod is drilled and carries a jet at the upper end from which an oil spray is directed into the piston crown for cooling purposes. The piston is aluminium with three wedge-type compression rings and two wedge-type oil-control rings. The camshaft is of the high-lift type, and the exhaust valve is sodium cooled, both exhaust and inlet valves being stellite faced and working on stellite inserts.

The engine is cooled evaporatively with ethylene glycol, an auxiliary condenser being added to the standard CFR unit to provide sufficient capacity. The lub. oil system is fitted with an oil heater for rapid warm-up and also with a cooler for temperature control during operation.

The engine is coupled to a dynamometer suitable for measuring the b.h.p. output, and arranged for motoring tests so that friction losses and knock-limited i.m.e.p. may be determined.

Operating conditions are:—

Speed	1800 r.p.m.
C.R.	7 : 1
Spark advance	45° b.t.d.c.
Coolant temperature	375° F.
Intake-air temperature	225° F.
Lub.-oil temperature	165° F.

The method of test is generally similar to that used in the Pegasus and CFR engines already described, and involves determination of mixture-response curves on the test sample(s) and reference fuel(s) using a standard degree of knock set aurally. A detonation indicator may be used if desired. The same basic F.4 procedure is used both in the U.S. and Great Britain, although there are a few differences in plotting and expressing test results.

The British method is to report in terms of relative performance in comparison with the 100/130 grade specification reference fuel, S (technical *iso*octane) + 1·25 ml T.E.L/U.S.G., thus:

$$\text{Rich-mixture rating of test fuel} = \frac{100 \times \text{i.m.e.p. of test fuel at specific fuel consumption of reference fuel peak}}{\text{i.m.e.p. of reference fuel at peak}}.$$

The same reference fuel is used irrespective of the rating level of the test sample.

The U.S. method is to determine, by bracketing, the reference-fuel blend which has the same knock-limited i.m.e.p. as the test sample. The rating of the sample is obtained by linear interpolation between the knock-limited i.m.e.p. values for the sample and bracketing reference fuels at the fuel–air ratio for maximum knock-limited i.m.e.p. of the lower bracketing reference fuel. Up to and including 100 octane, the reference fuels used are pure *iso*octane with *n*-heptane or secondary reference fuels S (technical *iso*octane) and M (low O.N. stock). Results are expressed as a rich-mixture O.N. Above 100 O.N. blends of *iso*octane (or S) and T.E.L. are used. The matching blend is then expressed as a performance number, using a standard conversion curve which expresses the knock-limited power of

*iso*octane plus various concentrations of T.E.L. as a percentage of that of *iso*octane clear.

From the mixture-response curves, determined on the test samples and necessary reference-fuel blends, the performance of the former can be readily obtained at any specified mixture strength. Specification conditions often require that not only shall a sample have a minimum performance at the mixture strength corresponding to the reference fuel peak, but that it shall at least be equal to the reference fuel over a wide fuel–air ratio range.

F.4 Rich-Mixture Rating Scales.

The sole reason for adopting the reference fuels S and M was apparently that they give a familiar scale, similar to that of the primary reference fuels *iso*octane–normal heptane and *iso*octane–lead, which have been in use for a number of years for ordinary knock testing. The use of a reference fuel of the type used for the earlier Pegasus tests was not

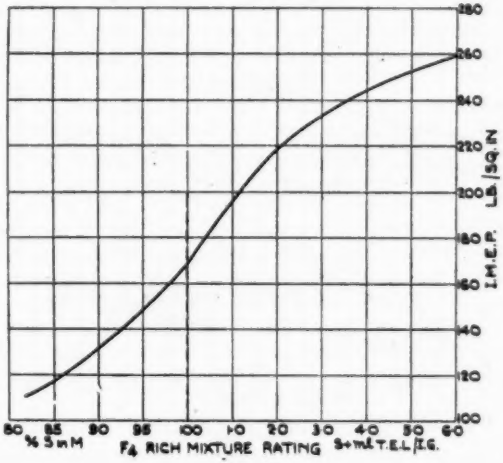

Fig. 11.

Relationship between power output and rich-mixture rating for the F.4 engine.

considered because of the difficulties of reproducing such a fuel in the various centres throughout the world; furthermore, fuels of this type are prone to weathering, with consequent alteration of rich-mixture performance.

The reference fuels and rating scale adopted suffer from three distinct disadvantages. First, the reference-fuel blends do not have the same shape of mixture-response curve as those of normal production fuels, and the reference fuels generally peak at a higher specific fuel consumption. Secondly, the scale is discontinuous with a sharp break at 100 per cent S. This is illustrated in Fig. 11, which shows power output plotted against reference-fuel composition. Thirdly, it is practically impossible to make blending calculations from ratings on this scale.

In order to make the scale suitable for blending calculations it was proposed in the U.S. to convert ratings to "Reference I.M.E.P." by means of an average curve of I.M.E.P. versus 3-C rating. As has already been stated the method adopted in the U.K. is to use a relative rating scale similar to that used for Pegasus and Hercules testing, with the 100/130 grade specification of S Ref. Fuel + 1·25 ml/U.S.G. as the reference fuel.

These rating scales are based upon measurement of power output, and for this reason give non-linear blending relationships. If the ratings of a series of binary blends, as measured by either the "Reference I.M.E.P." or the "per cent S + 1·25" scales are plotted against composition, the resulting relationship is usually curved.

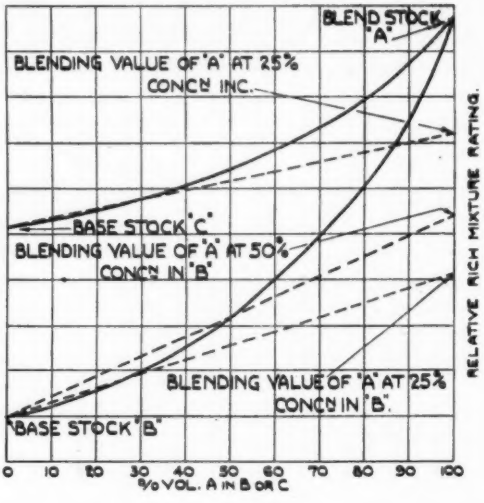
BLEND STOCK "A"
BLENDING VALUE OF "A" AT 25% CONCN INC.
BASE STOCK "C"
BLENDING VALUE OF "A" AT 50% CONCN IN "B"
BLENDING VALUE OF "A" AT 25% CONCN IN "B".
BASE STOCK "B"
RELATIVE RICH MIXTURE RATING.
0 10 20 30 40 50 60 70 80 90 100
% VOL. A IN B OR C

FIG. 12.

THE DEPENDANCE OF BLENDING VALUES, ON RELATIVE-RATING SCALES, ON CONCENTRATION AND PERFORMANCE OF BASE STOCK.

This leads to considerable difficulty in blending and blending calculations because of the dependence of the blending values of a component upon the concentration, the performance level of the base stock, and to a lesser extent, the composition of the base stock. The dependence of such blending values on concentration of the blend stock and performance level of the base stock is clearly illustrated in Fig. 12.

It will be seen that in order to calculate a blend composition of a desired rich-mixture rating or to calculate the rich-mixture rating of a blend of known composition, it is necessary to know the blending values of the components at the concentration in which they will be used, and in a base stock of performance level similar to that of the final blend.

Numerous attempts were made to obtain F.4 blending values to enable the rich-mixture rating of a blend to be calculated arithmetically from the

known composition. A non-linear blending chart was used by the A.I.O.C. laboratories, originally for Pegasus testing and later for F.4 testing, but this graphical method proved somewhat laborious. In the U.S. reciprocal Reference i.m.e.p.s were found to be substantially additive and this method of calculation was used to some extent.

The first truly linear rating scales to be used were based on blends of S and M with a constant addition of T.E.L. These were selected on the assumption that most aviation-fuel components obey the same blending law and that if ratings are made in terms of equivalent blend of two reference fuels, which also obey the law, then the rating–composition relationship for any series of blends should be linear.

Some of the earliest work in this connexion was described in a private communication from the Standard Oil Development Company.[8]

With few exceptions, ratings in terms of equivalent blends of the reference fuels S + 4 ml T.E.L/U.S.G. and M + 4 ml T.E.L/U.S.G. are substantially linear on a volume-composition basis, but the upper limit of the scale is below the limit of the F.4 method. Another pair of reference fuels, namely S + 20 per cent toluene + 4 ml T.E.L/U.S.G. and M + 20 per cent toluene + 4 ml T.E.L/U.S.G., were used to extend the scale and these ratings have also been shown to be generally linear.

Scales such as the above have not been generally adopted, however, although similar rating scales have been examined by various official bodies.[9] A more widely adopted linear-rating scale is known as the Index Number Scale. This scale was developed by the Aviation Gasoline Advisory Committee to the U.S. Petroleum Administrator for War and consists of an arbitrary non-linear blending chart calibrated in terms of conventional ratings on which most series of binary blends give a linear plot. The non-linear scale is divided linearly, and the linear divisions numbered to agree as closely as possible with the U.S. Army–Navy Performance No. Scale. This latter scale is based on the mean increase in knock-limited power output from a number of full-scale engines, expressed as a percentage of that obtained for S reference fuel, for the usual range of reference fuels S + T.E.L.

The index-number scale has been in regular use by the Anglo-Iranian Oil Co. Ltd. in the aviation-fuel blending operations since 1943 and has proved exceptionally useful. Provided the ratings (index numbers) of the individual components are accurately known the rich-mixture rating of a multi-component blend may be calculated with an accuracy approaching that of the engine test itself.

Some exceptions to the linear blending rule have been found, notably the naphthenes such as *cyclo*pentane and *cyclo*hexane and the *ortho*alkylbenzenes. The blending curves of the naphthenes are usually sufficiently linear up to about 40 per cent concentration, to have no significant effect on blending calculations, but the *ortho*alkylbenzenes present some difficulty. This is evident from Fig. 13, the shape of the blending curves being such that when present in concentrations up to about 20 per cent volume these compounds depress the rich-mixture rating, whilst at higher concentrations they improve it.

It should be noted that the three linear blending scales described are fundamentally the same, differing only in the derivation and method of

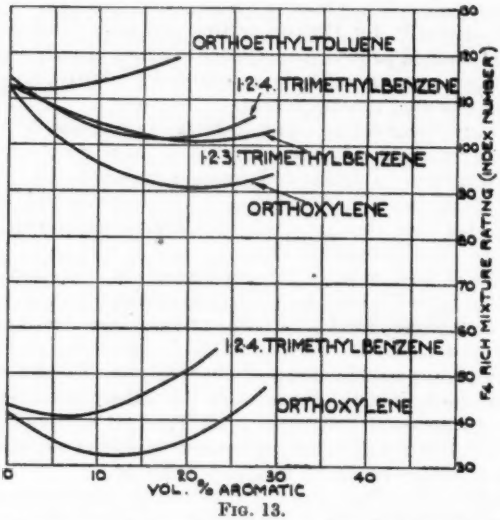

FIG. 13.

RICH-MIXTURE BLENDING CURVES OF ORTHOALKYLBENZENES.

TABLE II.

Component.	Purity, %.	O.N. (CFR.MM.).			F.4 Index no.	
		Neat.	+4·0 ml T.E.L/I.G.	+5·5 ml T.E.L/I.G.	+4·0 ml T.E.L/I.G.	+5·5 ml T.E.L/I.G.
Abadan C_4 alkylate	—	94	110·5	113	146	156
„ „ „	—	92·5	109	111	142	152
„ C_3 „	—	90	106	108	—	138
„ hydrocodimer	—	94	110	113	150	160
„ *iso*pentane	—	89	110·5	114	136	139
„ isohexane cut	—	80	99	102	98	112
„ *iso*heptane cut	—	74	88·5	91	103	116
„ aromatic extract	75 aromatics	84	90	91	147	155 *
„ aromatic extract	95 „	98	—	—	—	203 †
„ straight-run gasoline	—	70	87	90	—	54
„ straight-run benzene	—	60	79	82	30	45
Benzene	99·5	—	—	—	—	207
Toluene	99·3	—	—	—	—	250
*ortho*Xylene	*ca* 99·5	—	—	—	—	−11 *
*meta*Xylene	99·4	—	—	—	—	284
*para*Xylene	98	—	—	—	—	294
Ethylbenzene	98·3	—	—	—	—	267
1 : 2 : 3-trimethylbenzene	98	—	—	—	—	34 *
1 : 2 : 4-Trimethylbenzene	99·5	—	—	—	—	43 *
1 : 3 : 5-Trimethylbenzene	98·5	—	—	—	—	293
*ortho*Ethyltoluene	99·7	—	—	—	—	142 *
*meta*Ethyltoluene	99·6	—	—	—	—	245
*para*Ethyltoluene	98·8	—	—	—	—	265
*iso*Propylbenzene	>99	—	—	—	—	272
tert.-Butylbenzene	99·7	—	—	—	—	306
Para-cymene	>99	—	—	—	—	282
Cymene (mixed *ortho para*)	>99	—	—	—	—	236

* 15% concentration. † 10% concentration.

numbering, since there can be only one scale capable of straightening a series of curves obeying the same basic equation. It must also be understood that none of these scales can be used for calculations involving two or more components with differing amounts of T.E.L., but can only be applied at a given T.E.L. content which is constant for all the components under consideration.

A large number of determinations of F.4 blending values of aviation-fuel components and pure hydrocarbons were made at Sunbury, some of the more important results being given in Table II.

Conclusion.

The work described in this paper was of inestimable value to the major war task of the Abadan refinery of the Anglo-Iranian Oil Co. Ltd., namely to produce the maximum quantity of 100 O.N. fuel for the Allied Air Forces. When it is recalled that, in 1939, there was practically no production of such fuel in Abadan, whilst in 1945 the production rose to over 1 million I.G. per 24 hr, it will be seen what a tremendous achievement was made. The maximum production of 100 O.N. fuel actually amounted to rather more than 8 per cent of the crude oil processed through the refinery, and since there were no catalytic-cracking facilities in Abadan this was produced almost entirely from the benzine fraction of crude, the yield on this fraction being approximately 25 per cent. It is to the credit of all concerned that, with the exception of relatively minor quantities of pyrolysis benzole and cumene produced for short periods, this huge production was reached by blending essentially straight-run products with the synthetic *iso*paraffins, without which 100 O.N. fuel cannot be made in quantity.

The authors wish to point out that the work described represents the efforts of a team of the technical personnel of the company, and they also wish to thank the chairman of the Anglo-Iranian Oil Company for permission to publish this paper.

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AN AUTOMATIC INDICATOR FOR COLOURED FUELS FLOWING IN A PIPELINE.

By J. Savage * and M. Squires.†

Abstract.

An instrument has been developed which gives an automatic indication of a change in the colour of a liquid flowing in a pipeline. Use is made of the differences in light absorption of differently coloured liquids. The instrument has been specifically applied to fuel changes in a pipeline, but the method is capable of wide application where two liquids of differing colours are concerned. Between two successive plugs of say fuel A and B, a mixture occurs of both A and B. This is due to turbulent mixing and diffusion during the flow in the pipe. In general there is a fairly linear change in concentration between 100 per cent of A and 100 per cent of B, with a corresponding colour change.

A small quantity of fuel from the pipeline is run through a pressure-reducing valve into an absorption tube, which forms part of an optical pipeline unit. A beam of light is passed through the tube, and falls on a photo-cell system, the output of which is fed into a triggering circuit, which forms the basis of the indicator. Electro-magnetic relays, operated by the triggering circuit, actuate the warning lights and audible alarm.

Introduction.

In oil-pipeline operation several grades of fuel may be run through successively. The duration of the period of change-over from one fuel to another at a receiving point depends on a variety of factors, and is of the order of 5 to 10 min., but rather longer where the fuel is being pumped over very long distances.

This period of change-over is characterized by a mixture of two fuels passing in the pipeline, the change in concentration from 100 per cent of the first fuel to 100 per cent of the second fuel being fairly linear with time. It is frequently undesirable that a large proportion of this mixture should be run into either of the tanks receiving the separate fuels, and a method of warning the operator when a change-over of fuels is occurring is therefore required.

Several methods of change-over detection are at present in operation. In most cases, the pipeline is tapped at or near the receiving station. Fuel is passed through a pressure-reducing valve, and into a glass chamber to facilitate visual observation of colour changes, or into a convenient vessel for the determinaton of specific gravity. The fuel passing through these systems is then run into a waste tank.

Both methods have objectionable features. A primary objection is that continuous observation is necessary over a prolonged period, unless the change-over time can be closely predicted. Where colour changes are used as the criterion, insensitivity must be met with. For example, in changing from a red-coloured fuel to one that is dyed green, yellow, or is colourless, it is necessary for about 40 per cent of any of the latter to be present before it can be certain that the colour has materially changed.

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The method of the determination of specific gravity is subject to the limitation that this property of any one grade of fuel may vary over a considerable range due to the varying proportions of hydrocarbons present or to temperature changes. Where there is a possibility of the permissible range of specific gravity of one fuel overlapping the range of a second fuel in the pipeline, the determination of specific gravity as a criterion of change-over is not satisfactory.

In order to obviate some of the difficulties described, an automatic system has been developed for giving warning of a change of fuel passing in a pipeline. The instrument consists of an assembly of three units; the system being divided in this way for convenience in operation and installation.

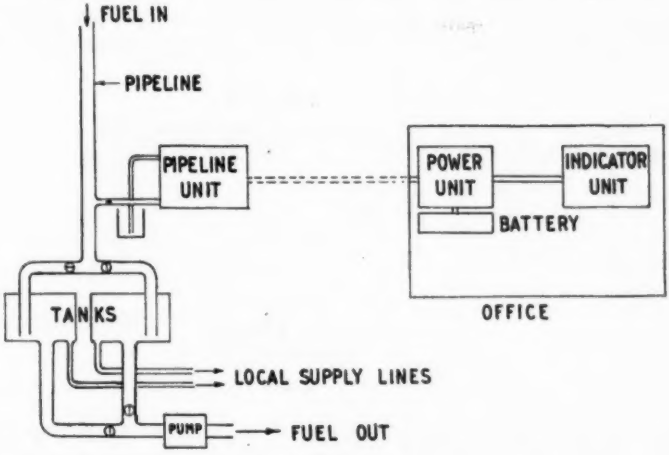

FIG. 1.

SCHEMATIC ARRANGEMENT OF THE FUEL INDICATOR AT A PIPELINE STATION.

The schematic arrangement of the instrument at a receiving station is shown in Fig. 1.

The pipeline unit is fixed near to a tapping point on the line, the indicator unit being conveniently placed in an office possibly remote from the pipeline. The operator may then be warned of a fuel change-over and give any instructions necessary, with no inconvenience and the minimum interruption of his other duties.

The power-supply unit is preferably located away from the indicator, so that the rotary converter incorporated for battery operation is inaudible to the personnel. All three units are brought into operation by a single switch on the indicator unit.

THE PIPELINE UNIT.

The pipeline unit is shown in Figs. 2 and 3. The source of light *S* (Fig. 2) is a 12-V, 36-W bulb having a straight or V-shaped filament. The light

from S is passed as a slightly divergent beam through the absorption tube, T, and a filter, F, on to the photo-cell, P_1. The biconvex lens, L, has a focal length of 1·5 in and an aperture of 2 in.

Light from the source S also passes through a rectangular adjustable diaphragm, D, to which is attached a diffusing screen, G, of flashed opal glass, from which the light is scattered so that a proportion completely fills the second photo-cell, P_2. A similar filter, F, is also fixed between the diffusing screen, G, and the photo-cell, P_2. Fuel from the pipeline runs into the absorption tube, T, at the bottom and out at the top. A baffle fixed near the bottom of the absorption tube prevents any air bubbles in the fuel from passing through the actual light beam, guiding them outside the beam and out at the top.

The tube has thick glass end plates, capable of withstanding at least 80 p.s.i. pressure. Greater pressures exist in the pipeline, but as the fuel entering the absorption tube is first passed through a pressure-reducing

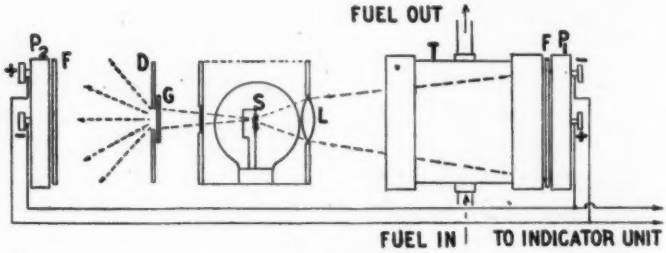

FIG. 2.

OPTICAL ARRANGEMENT OF THE PIPELINE UNIT.

valve, the pressure exerted on the tube T is considerably less than the figure given. The glass end plates are easily removable for cleaning purposes, being of the screw-on type, and petrol-resistant washers seal the tube against leakage.

A Wratten minus red filter was chosen for obtaining sharp differentiation between M.T. spirit (dyed red) and 100-octane (dyed green). The red light transmitted by the M.T. spirit is practically all absorbed by this filter, so that only a low illumination is received by the photo-cell P_1. On the other hand, the light transmitted by 100-octane, 72-octane, and kerosine, which are green, yellow, and colourless respectively, is freely transmitted by the minus-red filter. Other filters could be used to differentiate against a fuel other than M.T. spirit.

The photo-cells used in the pipeline unit are Eel Selenium Multiple Cells, Type M. 1. This type of selenium photo-cell has the property of developing a high voltage in an external resistance of the order of 1 megohm. The voltage change with changing illumination is of the order 0·1 V per foot candle, for the illumination range of 0 to 30 footcandles, with an external resistance of 1 megohm. It was considered advisable to adopt such a selenium photo-cell for use with the instrument, as these cells had a smooth response curve to all visible radiation, and were therefore able to deal with

all colours of liquids. The system is compensated against changes of light intensity, due, say, to battery fluctuations or lamp deterioration as follows.

In the pipeline unit the photo-cells P_1 and P_2 are connected in series and in opposition, and connexions are made to the indicator unit as shown in Fig. 2. Changes in light intensity affect both cells more or less equally, and thus the resulting voltages cancel. On the other hand fuel changes affect only one cell and hence register on the indicator. For operation, the photo-cells are balanced by pre-setting in the following manner. The absorption chamber T is filled with M.T. spirit, and only a small illumination reaches the photo-cell P_1. The output from P_1 is then neutralized by adjusting the area of the diaphragm D so that there is no current in the leads to the indicator unit, and consequently no voltage is applied to the

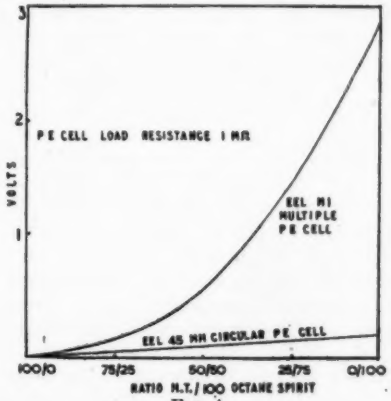

FIG. 4.

VOLTAGE OUTPUT FROM PIPELINE UNIT FOR MIXTURES OF M.T. AND 100-OCTANE SPIRITS.

grid of the first valve. The small output voltages from P_1 and P_2 oppose each other in the grid circuit of the first valve.

As a check on this adjustment, a switch is provided on the indicator unit, which, when depressed, breaks the photo-cell connexions to the valve grid. When the photo-cell circuit has been correctly balanced a depression of this switch should not affect the valve anode current, showing that no voltage is being supplied by the photo-cell system to the valve grid.

When the pipeline is passing M.T. spirit the absorption chamber T is consequently filled with this fuel. There is then no applied voltage to the grid of the first thermionic valve. When a second fuel begins to arrive, this enters the absorption tube, and the illumination on the photo-cell P_1 gradually increases, due to the selective action of the minus-red filter. The result is that a slowly increasing voltage is applied to the first grid of the indicator unit. The rate at which this voltage excursion occurs is shown graphically in Fig. 4, for various admixtures of M.T. spirit and 100-octane. Curves are shown for the Type M.1 and the more usual type of selenium photo-cell. It is at once clear that the multiple photo-cell produces far greater voltage excursions on the valve grid. Similar curves are obtained

with admixtures of M.T. spirit and either 72-octane or kerosine, except that in these cases greater voltage excursions are produced in passing from 100 per cent M.T., than with 100-octane spirit, with corresponding increases in sensitivity.

In operation, during the change-over from M.T. to 100-octane spirit there is then a slowly increasing voltage output from the photo-cells from zero to about 2·9 V. In changing in the reverse direction, the voltage output from the photo-cell system slowly falls from 2·9 V to zero. These voltage changes are utilized by the indicator unit to give the visible and audible warnings to the operators.

The Indicator Unit.

The indicator consists essentially of a box containing the electronic circuit and magnetic relays. It embodies also the warning and control systems comprising coloured lights, a bell or buzzer, a four-position control switch, and a main on-off switch. Situated at the rear are certain preset adjustments. The latter are set up on installation, or replacement of components, and should require very little further attention.

For purposes of explanation it will be convenient to describe in terms of two specific fuels, such as M.T. and 100-octane spirit. These are conventionally dyed red and green respectively, and accordingly it would be arranged that the two indicator lamps are also red and green. Obviously, other colours could equally well be used for other coloured liquids.

Let it be supposed that initially, M.T. spirit is flowing along the pipeline, and the instrument is adjusted to operate at 5 per cent contamination. The red lamp will be glowing. When a change-over is made to 100-octane, there will be present initially, M.T. spirit with a small but increasing admixture of 100-octane. When 5 per cent of admixture is present, the green lamp will illuminate, and the bell will ring. Both lamps now show. The operator now initiates any necessary tank-switching action, and shifts the control switch one step. This stops the bell and leaves both lamps illuminated. Meanwhile, the fuel in the pipe contains an increasing percentage of 100-octane, reaching eventually 95 per cent. The bell now commences ringing again, and the red lamp is extinguished, leaving the green one alight. The operator initiates further tank-switching action, and gives the control switch a further turn, which stops the bell, and leaves the green lamp alight. This state of affairs continues for 95 per cent or any higher percentage of 100-octane present. For a reversion to M.T. spirit, a corresponding process occurs.

It will be noted that at every change of state the control switch is moved forward one step. Since incorrect use of this switch might give misleading results certain preventive measures have been incorporated. Thus the switch is prevented, by means of a ratchet, from being rotatable in the wrong direction. Also, by means of a spring and lever arrangement, it has been made impossible accidentally to move the switch through two steps. It is, therefore, impossible to throw the device out of adjustment except by deliberate intention, provided that the two fuels alternate in the manner described above. It is not necessary for there to be a smooth progression from one type of fuel to the other. If, however, the switch is rotated more

than one step, the situation can be restored immediately by rotating a further three steps, thus bringing it to its original position. If for any reason the correct position is not known this could usually be checked by an inspection of the pipeline unit.

The Circuit.

This consists essentially of two thermionic valves (V_1, V_2) A.M. Type VR. 65, and an electromagnetic relay of the standard G.P.O. type. The

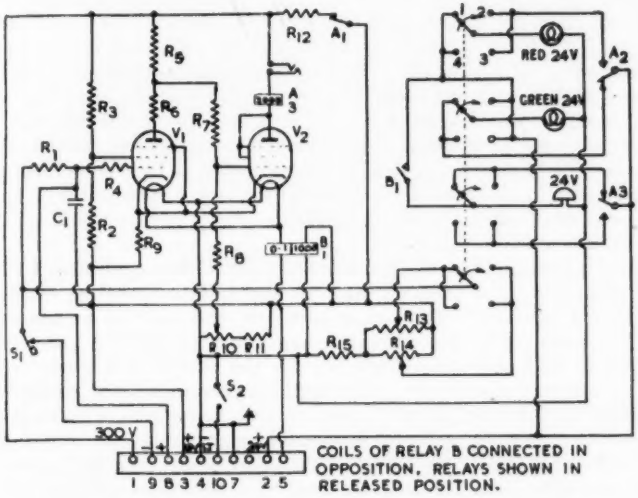

Fig. 5.

CIRCUIT OF INDICATOR UNIT.

Resistances :

R_1	1 MΩ, ¼W, 20%	R_8	5·6 kΩ, ¼W, 5%
R_2	5·6 kΩ, 8W, 5%	R_9	47 Ω, ¼W, 5%
R_3	3·3 kΩ, 5W, 5%	R_{11}	25 kΩ, 1W Potentiometer
R_4	4·7 kΩ, ¼W, 20%	R_{11}	12 kΩ, ¼W, 20%
R_5	270 kΩ, ¼W, 5%	R_{13}	30 kΩ, 6W, 5%
R_6	47 Ω, ¼W, 20%	R_{13}, R_{14}	20 kΩ, 1W
R_7	2·2 MΩ, ¼W, 5%	R_{15}	12 kΩ, ¼W, 20%

Condensers :

C_1 0·5 μF

Valves :

V_1, V_2 *VR65*

Switches :

S_1 Press button, ref. 10F/11062
S_2 On-off, ref. 10F/10338

grid of V_1 (Fig. 5) is connected to the photo-cell circuit, while the relay is in the anode circuit of valve V_2. It is the combination of the relay contacts and the control switch contacts which connects the lamps and the bell to the 24-V source, or disconnects them severally, as required.

The two valves comprise a D.C.-operated "triggering" circuit. That is to say that they and their associated circuits can only be maintained in one or other of two stable conditions. In one state the anode current of V_1 is cut off while that of V_2 is at some value suitable to maintain the relay in operation. In the other state, V_1 is "on" while the anode current of V_2 is reduced sensibly to zero. A circuit of this kind, forming as it does a thermionic on-off switch in which no intermediate conditions are possible, is singularly well adapted to the operation of an electromagnetic relay by means of a voltage source, especially when power may not be drawn from the latter. The particular condition of the circuit at a given time is governed by the steady voltage level applied to the control grid of V_1. This is governed in turn by the voltage supplied by the selenium cells, and the setting of potentiometers R_{13} and R_{14}. The latter, being connected across a regulated 18-V supply, can be set to apply a proportion of this voltage, with respect to earth to the control grid of V_1 in series with the cell voltage. One or other of these potentiometers is operative, according to the position of the main control switch. The selection is governed by whether the next fuel change-over expected is in the neighbourhood of 95 per cent M.T. spirit–5 per cent 100-octane, or in the neighbourhood of 5 per cent M.T. spirit–95 per cent 100-octane.

A third potentiometer, R_{10}, governs the bias voltage applied to V_2 in its "on" condition, thus ensuring that an appropriate operating current is available for the relay. In point of fact, the relay and the parameters of the valve circuit are so chosen that the appropriate setting of R_{10} also gives a condition of high operating sensitivity for the circuit as a whole, with a sufficient measure of stability. It is found in practice that an excursion of less than 0·05 V at the grid of V_1 can actuate the circuit: a value readily given by the selenium cells for fuel colour changes far too slight to be detected by eye. Thus, a mixture consisting of 40 per cent M.T. spirit and 60 per cent 100-octane, is not easily distinguishable by eye from 100 per cent M.T. spirit even by direct comparison, but a contamination of 100-octane spirit with as little as 5 per cent spirit will operate the indicator.

It is found that a progressive change in fuel colour produces corresponding changes in valve-anode currents at points outside the range of instability which governs the operation of the circuit. These changes occur, however, for values of current either well below the operative value for the relay, or well above the release value as the case may be, so that the perfectly definite "on" and "off" requirements are unaffected, and no uncertainty of action results, as would occur with a normal amplifier. The effect, however, is highly useful since it enables a very sensitive check to be made of the selenium-cell compensation. This function will be described under the heading of "Alignment."

In describing the sequence of actions occurring in the circuit, it will be assumed that alignment has been carried out. This involves among other things, that the selenium cells give no resultant voltage output when 100 per cent M.T. spirit flows in the pipeline. In these conditions the control grid of V_1 is connected through to the slider of potentiometer R_{13}, which is adjusted so that V_1 is "off" and V_2 is "on," *i.e.*, the relay is operated. With the control switch in the position shown in Fig. 5, the bell is inoperative, and the red lamp is lighted through switch contacts.

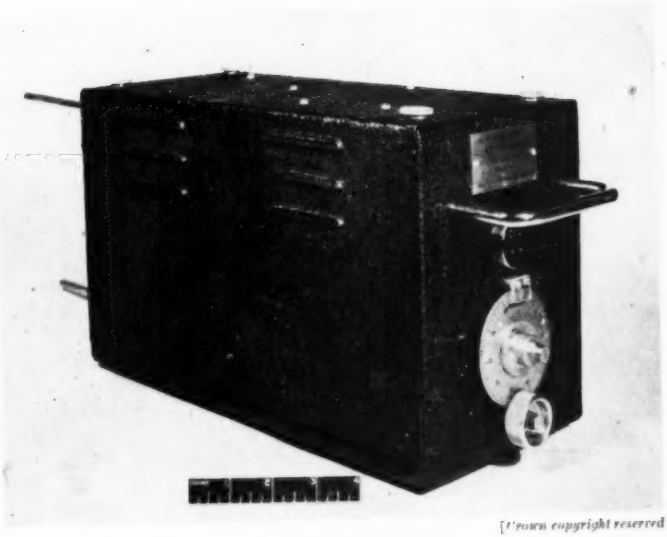

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FIG. 3.
PIPELINE UNIT.

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FIG. 6.
INDICATOR UNIT.

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FIG. 8.
POWER UNIT.

With sufficient green fuel present A/3 releases; the red light is unaffected; the green lamp lights through contacts A_2; the bell rings through contacts A_3. The operator turns the switch one step clockwise to position 2. The grid of V_1 is transferred by the switch to potentiometer R_{14} causing $A/3$ to re-operate. The red lamp therefore stays alight through contacts A_2; the green light stays operated through the switch contacts; the bell is suppressed at contacts A_3. When the fuel is almost completely green, relay A/3 releases; the red light is suppressed at contacts A_2; the green light stays illuminated through contacts A_3; the bell rings through contacts A_3. The operator now turns the switch to position 3. The grid of V_1 remains connected to potentiometer R_{14} and so A/3 is still released. Hence the red light remains suppressed; the green light remains on through the switch contacts; the bell is suppressed. A small amount of red fuel eventually appears in the liquid mixture, causing A/3 to operate. The red light comes on through contacts A_2; the green light stays on; the bell rings through contacts A_3. The operator moves the switch to position 4. The grid of V_1 is transferred to R_{13} causing A_3 to release. The red light stays on through the switch contacts; the green light is connected through contacts A_2; the bell is suppressed at contacts A_3. Eventually the liquid mixture is almost entirely red, and relay A/3 operates. The red light stays on; the green light is suppressed at contacts A_2; the bell rings through contacts A_3. The operator turns the switch to position 1. The red light remains on; the green light is suppressed at contacts A_2; the bell is suppressed at contacts A_3; and the cycle is complete.

Alignment of the Pipeline and Indicator Units.

The indicator, pipeline, and power units are connected and allowed to warm up. The potentiometers, R_{10}, R_{13}, R_{14}, are rotated to their extreme anti-clockwise positions, the test meter plugged into the jack provided at the back of the indicator, and the absorption chamber in the pipeline unit is filled with the liquid which transmits less light—in the case considered above, M.T. spirit. The control switch is rotated until only the red light shows, and the bell does not ring. The anode current of V_2 is now read on the meter. This will be such as to operate the relay. The push button S, also provided on the back of the indicator, is operated and, if the selenium cells are properly compensated for variations in light intensity, operating the push button, which merely disconnects the cells, should not affect the meter reading. If it does, then the positioning and/or screening of the compensating cell are adjusted accordingly. Two or three operations should suffice to complete this part of the alignment.

R_{13} is now rotated clockwise until the bell rings and the green lamp is illuminated. Now R_{13} is rotated slightly back until the original condition is just restored. The meter reading is now adjusted to about 12 to 14 mA by means of R_{10}. The process is then repeated. Probably the meter reading will be other than that required, but here again, two or three repetitions should suffice to complete the adjustment.

The liquid in the absorption chamber is now replaced by that which lets through more light, *i.e.*, the 100-octane spirit. The control switch should now be set in the position in which the green light shows, but the bell does

not ring. Potentiometer R_{14} is rotated clockwise until the bell rings and the red lamp lights. Finally R_{14} is rotated back again just far enough to restore the initial condition.

With the adjustments completed, it is found that dilutions of the order of 5 per cent or even less—depending on the pair of colours involved—will operate the device. For each adjustment the main switch must of course be set to bring the appropriate potentiometer R_{13} or R_{14} into circuit.

Precautions Against Breakdown.

Consideration has been given in the design to the need for certain safety devices. Forms of breakdown are possible in the apparatus which might result in misleading indications until their existence was discovered. On the other hand it was felt that excessive precautions would lead to a state of affairs where breakdowns in the precautionary measures themselves might be almost as likely to occur as in the main apparatus itself.

It was, however, considered necessary to give warning in the events of (*a*) breakage of the light illuminating the photo-cells (being remotely situated, a fault there would not readily be detected), or (*b*) failure of either of the thermionic valve heaters. Relay B/1 fulfils this function. It has two windings: one of high resistance (0·1 ohm) being connected in the heater-lamp circuit as shown in Fig. 5. The windings are connected in opposition so that, with the apparatus in good order, this relay is not operated. In this condition a total current of 1·3 amp flows in the low-resistance winding. Breakage of the lamp filament interrupts this current, thus operating the relay. Breakage of both valve heaters would have the same effect. Breakage of only one valve heater would only reduce the current to 0·65 amp—a change ratio of only 1 to 2.

Such a ratio is not considered sufficient to ensure reliable operation of the relay. The inclusion of the second, or high-resistance winding overcomes this difficulty. It ensures that the magnetic flux affecting the relay approximates to zero when the lamp and valves are intact. The reduction of current to 0·65 amp therefore results in the ratio of effective "hold" to "release" flux in the relay approaching infinity, or at all events, very much greater than two-to-one. Thus the conditions for reliable operation of this relay are satisfied. Its contacts are so arranged that on operation the bell is connected via contacts B_1 to the 24-V source, irrespective of the condition either of relay A/3 or of the main control switch. In the presence of a fault, therefore, the operator will find that the bell rings continuously, and cannot be switched off, except at the main power switch. Failure of the L.T. supply would of course be apparent from failure of the lamps to light.

The Power Pack.

This is an embodiment of standard devices designed to operate the instrument from a 24-V D.C. source. Two carbon-pile stabilizers are provided, giving 18 V for a wide range in fluctuation of the 24-V source. One carbon pile supplies a rotary converter giving a D.C. output of 450 V. The other carbon pile provides current for the valve heaters and the absorption-cell illumination. The circuit is shown in Fig. 7.

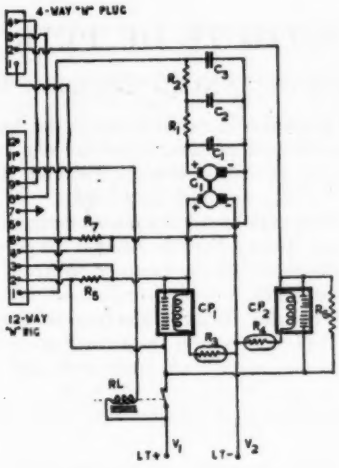

FIG. 7.

CIRCUIT OF POWER SUPPLY UNIT.

Resistances :		Condensers :	
R_1, R_2	1·8 kΩ, 4 W	C_1, C_2, C_3	8 μF, 1200 V
R_3, R_4	Ballast	CP_1, CP_2	Regulator, type 19
R_5, R_6	6 Ω	G_1	Transformer, rotary type 46
R_7	3·5 Ω, 12 W	RL	Contactor

ACKNOWLEDGMENTS.

The writers wish to acknowledge the considerable contributions to the development of the instrument of F/Lt W. M. Bielak and J. D. Broatch (Chemistry Division), together with D. Brechner (Radio Dept.) of the Royal Aircraft Establishment.

Thanks are also due to Messrs. Macmichael Radio Ltd., and Messrs. Evans Electroselenium Ltd. for the production of the prototype indicator units and photo-cells respectively. Finally, thanks are due to the Petroleum Board for their permission to make the preliminary tests at their pipeline station at Aldermaston.

THE INSTITUTE OF PETROLEUM.

THIRTY-FIFTH ANNUAL GENERAL MEETING.

THE Thirty-Fifth Annual General Meeting of the Institute of Petroleum was held in the lecture hall of the Royal Society of Arts, John Adam Street, Adelphi, London, W.C.2, on Friday, April 30, 1948. The President, Sir Andrew Agnew, C.B.E., occupied the Chair.

THE SECRETARY (F. H. Coe) read the notice convening the meeting.

The Minutes of the Thirty-Fourth Annual General Meeting, held at Manson House, 26, Portland Place, London, W.1, on April 9, 1947, were read, confirmed, and signed.

The Minutes of a Special General Meeting of the Institute, held on Thursday, July 24, 1947, concerning the substitution of new By-Laws for the then existing By-Laws, were read, confirmed, and signed.

OFFICERS FOR THE SESSION 1948–49.

President.

THE PRESIDENT: Your Council have nominated E. A. Evans, and I am sure that that choice will be very popular. The formal induction of the new president will take place later this afternoon, when I hope to have the opportunity to say a little more about his appointment. For the present I submit the nomination of E. A. Evans as President, for formal approval by this meeting.

The nomination was unanimously approved, amid applause.

THE PRESIDENT: I am sure you would all wish me to congratulate our friend, Mr Evans, on his appointment and to wish him every success during his year of office.

Vice-Presidents.

THE PRESIDENT: The following nominations for vice-presidents have been made by Council, and I submit them for your approval:

E. B. Evans	J. A. Oriel
H. Hyams	C. A. P. Southwell
V. C. Illing	H. C. Tett

The nominations were unanimously approved.

Members of Council.

THE PRESIDENT: On this occasion no ballot was necessary for elections to Council, as twelve nominations were made to fill twelve vacancies.

THE SECRETARY read the names of members nominated for election to the Council in accordance with the By-Laws, as follows:

W. S. Ault	E. Stokoe
C. T. Brunner	E. J. Sturgess
T. F. Laurie	G. H. Thornley
H. E. F. Pracy	E. Thornton
D. L. Samuel	A. T. Wilford
G. H. Smith	W. J. Wilson

The members nominated were declared elected.

Hon. Treasurer and Hon. Secretary.

THE PRESIDENT: G. H. COXON has again been nominated by the Council as Honorary Treasurer, and C. CHILVERS as Honorary Secretary.

In submitting the names of these two gentlemen for re-election I am sure you would like to couple with the motion a vote of thanks to them for their splendid work during the past session. They well deserve our praise. We, as an Institute, are extremely fortunate in having two such first-class gentlemen occupying these very important positions, and I take it that everyone is heartily in favour of their re-election.

Mr Coxon and Mr Chilvers were unanimously re-elected.

Ex-Officio Members of Council.

The meeting elected the following as Members of Council, ex-officio, representing the Branches:

T. W. Ranson Mervyn Mason	*Northern Branch*
W. Robert Guy	*Scottish Branch*
R. B. Southall	*South Wales Branch*
C. D. Brewer V. Biske	*Stanlow Branch*

MEMBERS ELECTED AND TRANSFERRED.

The list of Honorary Members, Honorary Fellows, Members, Fellows, Associate Members, Associate Fellows, and Student Members elected or transferred during the year 1947 was laid on the table.

REPORT OF COUNCIL, 1947.

THE PRESIDENT: The Report has been circulated and I will, therefore, take it as read, and will ask the Chairman of the Council to comment on its more important features.

MR H. C. TETT (*Chairman of Council*): It is impossible, in a few words, to review even in outline the very broad scope of the work of the Institute. Most of this work, for which Council is responsible, is done by the Committees of Council rather than by the Council itself. A very great volume of this Committee work is of the kind that is rather taken for granted by those not directly concerned with it, and it does not lend itself particularly to colourful presentation. I have in mind the outstanding and important work which is done by the Committees on Publication, Standardization, and Education, and by those which deal with Branch activities, the By-Laws, with the election and transfer of members, with research, and with house and staff problems. This is the kind of work which flows continuously and in ever-increasing volume, and for which those responsible usually receive very inadequate thanks. It is none the less in and through those activities that the Institute lives and grows and serves its members and the whole of our great petroleum industry.

Before touching on a few matters which are, I think, of special interest I would, therefore, like to emphasize how much we are all indebted to the members, and especially to the Chairmen, of the Council Committees, to the Honorary Treasurer, the Honorary Secretary, and last, but by no means least, to the staff.

During 1947, 194 new members were elected, our total membership on

December 31, 1947, being 2214, which is exactly 50 per cent more than at the end of 1938. Our net gain in membership in 1947 was four times as great as in the last pre-war year. In the first few months of this year a further 240 applications have already been received, more than in the whole of 1947. It is a cause for great satisfaction that our membership is not only increasing, but that the rate of increase is itself rising rapidly.

The Cadman Medal was awarded in 1947 to R. P. Russell. His address at the Royal Institution, the dinner given in his honour by the Institute, and the lectures which he gave to the Branches were among the most successful functions the Institute has held.

Our Branches have been very active and successful during the year, and we regard them as a most important and vital part of the life of the Institute. The new London Branch was conceived during 1947 and, after much hard work on the part of the organizers, has now commenced with great success its active life.

We added to our publications during the year with the issue of the *I.P. Review*, which has been well received and which we shall try constantly to improve, but for which we need the help of all our members in providing suitable material.

We have also set up a new Public Relations Committee to help in bringing the work of the Institute to the knowledge of all those whom it can assist.

A great deal of thought has been given during the year to the finances of the Institute, particularly since our forward estimates indicate that there will be large deficits unless our present income is increased. The best way of securing additional income is by increasing membership, and already much has been done to this end. It is the opinion of Council that, with the increasing importance and expansion of the petroleum industry, and particularly of refining, in Britain, the Institute can look forward to very large increases in membership in the forthcoming years, particularly if it is successful in achieving its object of catering broadly for the interests of all those in the industry.

Even so, we do not foresee that increased membership alone will provide the finances which will be needed and we are, therefore, proposing to make it possible for companies to support the work of the Institute through company membership, provision for which is made in the new By-Laws which will be put to you later in this meeting.

Your Council feels that the Institute has made good progress during the year and can look forward to the future with confidence.

THE PRESIDENT: I feel sure we can all be very satisfied with the hard work that has been put in by the Council during a very busy year. I also feel sure that the members will be willing to adopt this Report. Before putting it formally to the meeting, I will ask if anyone has any questions, to which I am sure Mr Tett and Mr Chilvers will be able to reply.

No questions or comments were offered by the meeting concerning the Report, and on the motion of the President it was unanimously adopted.

APPOINTMENT OF AUDITORS.

On the motion of G. H. Coxon (*Hon. Treasurer*), seconded by A. T. Beazley, Messrs. Price, Waterhouse & Co. (*Chartered Accountants*) were re-appointed Auditors for the year 1948–49.

By-Laws.

Resolutions were submitted, as set out in the Agenda, for the alteration of By-Laws 5, 13, 16, 18, 33, 34, and 37.

The President: I want to say that the proposed amendment of the By-Laws will give the industry an opportunity to support the Institute on a broad basis. I know the industry is very conscious of the valuable assistance which the Institute has rendered, and that the opportunity of giving official support will be welcomed by all members of the industry.

H. Hyams (*Chairman of the By-Laws Committee*): I propose, with your permission, to take the resolutions as set out under Item 13 of the Agenda as read; and before formally proposing the adoption of the new By-Laws I would like to say a word in explanation.

The By-Laws were completely revised quite recently, the new By-Laws being adopted by the members at a Special General Meeting held on July 24, 1947.

Since then, as you, Mr President, have indicated, Council has felt that the membership of the Institute should be further broadened by encouraging the oil industry to take a greater interest in the Institute's work and activities.

The By-Laws have accordingly been revised to permit limited companies and partnership firms engaged in the petroleum or an allied industry to become non-corporate members of the Institute in a category to be known as Member-Companies. The amendments which were necessary to effect this are set out in Sections A and B of Item 13 of the Agenda. The qualifications and terms for admission to the Member-Company grade, as well as the privileges provided for Collective-Members and Member-Companies, are clearly set out in the proposed revised By-Laws printed on pages 3 and 4 of the Agenda paper. It is the Council's earnest hope that the proposed new By-Laws 13, 33A, and 37 will result in a considerable influx of members of the new grade, thus giving the Institute the additional moral and monetary support which we feel our work fully deserves.

I think it is worth quoting here the proposed new By-Law 13:—

> *Member-Companies.* "A Limited Company or a Partnership Firm which is engaged in the petroleum or an allied industry and which is interested in and is desirous of assisting in the work of the Institute may be elected a Member-Company by the Council."

Mr President and gentlemen, I have very great pleasure in moving the following resolution:—

> "That By-Laws numbered 5, 13, 16, 18, 33, 33A, 34, and 37 as set out on pages 3 and 4 of the official notice covering this Annual General Meeting be and are hereby approved and adopted as part of the By-Laws of the Institute, in substitution for and to the exclusion of the existing By-Laws numbered 5, 13, 16, 18, 33, 34, and 37."

T. Dewhurst (*Past-President*): I wish to second that proposal and to urge its acceptance at your hands.

There was no response to the President's invitation to the meeting to put questions, and the resolution was carried unanimously.

Adjourned.

No notice having been given of any further business, it was proposed by T. F. Laurie, seconded by T. R. Bird, and carried, that the meeting be adjourned until such time as the Council may decide, of which due notice will be given.

Vote of Thanks to President.

H. C. Tett: Before we leave, I think it would be the wish of all of us that we should accord a vote of thanks to our President, Sir Andrew Agnew, for presiding at this meeting. We shall have a further opportunity shortly to pay tribute to him, when we hear his Presidential Address; but I do wish to propose now a formal vote of thanks to him.

The vote of thanks was accorded with acclamation.

The President: Thank you, Mr Tett and gentlemen. It has been a great pleasure to me to be at this meeting.

The Annual General Meeting was adjourned.

Following an interval for tea, the members and guests of the Institute reassembled under the chairmanship of Sir Andrew Agnew.

Welcome to Guests from Overseas.

The Chairman: Before proceeding with the formal business of the evening I would like on your behalf to welcome L. C. Burroughs and James G. Detwiler, of the American Society for Testing Materials. These gentlemen have honoured the Institute by coming here to work with us on mutual problems connected with standardization.

They have brought with them a message from W. R. Boyd, Jr., President of the American Petroleum Institute, addressed to the Officers and Members of the Institute of Petroleum. The message reads:—

> "The American Petroleum Institute tenders to the Institute of Petroleum greetings and felicitations through its representatives, L. C. Burroughs and James G. Detwiler.
>
> "The American Petroleum Institute is fully conscious of the brilliant work of the Institute of Petroleum, and offers congratulations on the very worthy accomplishments in the field in which we are both interested."

I am sure you would wish me to reply to Mr Boyd on your behalf, and we propose to send a cable to him after this meeting, conveying our cordial greetings to the American Petroleum Institute. (Applause.)

Installation of President.

The Chairman: My first formal duty this evening is a very pleasant one; it is to instal the new president of the Institute. Council have nominated as President for the session 1948–49 E. A. Evans, who is with me on this platform, and the nomination has been duly approved at the Annual General Meeting this afternoon.

Mr Evans was first elected a member of the Institute in 1916, when he had the honour of being proposed for membership by Sir Boverton Redwood. He has been a Member of Council for fifteen years and was made a Vice-

ELLIOTT A. EVANS, M.I.Mech.E., F.R.I.C.
PRESIDENT.

[*To face p.* 892.

President in 1946. He has also recently been elected Chairman of the Standardization Committee, of which he has been a member almost from its inception in 1921.

Our new President is well known in petroleum circles throughout the world for his work over the past thirty years on lubricants and lubrication. He was one of the earliest pioneers of the use of chemical additives in lubricants. His many publications are sufficient indication of his reputation as a petroleum technologist.

He has also gained renown in the field of automobile research. He has done sterling work both for the automobile industry and the oil industry as Chairman for many years of the Automobile Research Committee of the Institution of Automobile Engineers. He became first Chairman of the Motor Industry Research Association when that body was formed in 1946.

Co-operation between our petroleum industry and the motor industry is an obvious fundamental necessity, since neither could have reached its present size and importance without the other. We are fortunate in having as our new president a distinguished member of the oil industry who has already done so much to foster such co-operation.

It is a high honour indeed to be elected president of the Institute of Petroleum, and it is one which Mr Evans has richly deserved (hear hear). The Institute has chosen well in the appointment of Mr Evans as its new president, and I am sure also that this appointment will give great pleasure and pride to the great and widely known commercial concern with which Mr Evans is associated.

It is with very great pleasure, therefore, that I ask him now to take his rightful place as your new president and occupy the chair at this meeting.

Mr Evans, formally occupying the Chair, vacated by Sir Andrew, who shook him by the hand and wished him well, was greeted with prolonged applause. He said: Sir Andrew, I thank you very sincerely indeed for your very kind words. I feel all too conscious of the fact that they are far too generous, and they make me feel that it is essential that I train my mind to think anew and re-orient myself to fit into the mosaic of petroleum technology. Whatever I have been able to do in the vast panorama of the science of petroleum has been only an approximation, however much I have hunted the elusive truth.

It is exceedingly difficult for anyone to follow a man of the outstanding ability of Sir Andrew Agnew, a man who has controlled the destiny of one of the largest business organizations in the country. He has many associations with other oil companies, and it is very difficult indeed to think of any man who has done so much for the petroleum industry. Not only in the petroleum industry has he won laurels, however. During the first world war he did yeoman service in Singapore; it is hardly necessary for me to repeat what he did in those days. Suffice it to say that he was rewarded with an honour from His Majesty the King, the honour of the C.B.E. It is difficult also to imagine a man of such great attainments and yet who has greater modesty—except, perhaps, another Scot! When he comes to a difficulty he approaches it with the delicacy of a bulldozer!

When the second world war started in 1939, Sir Andrew had retired; but he was recalled to play yet one more prominent part, a part which was even greater than any he had played previously. He was appointed

Chairman of the Petroleum Board, an organization of which you will hear a great deal, I hope, from Sir Andrew in his Presidential Address in a few moments. But I think it will be perfectly true to say that he was elevated to the very highest pinnacle in the petroleum industry, because not merely was he controlling one section of the industry, but the whole of it. It would also be true to say that the control did not end on the coastline of these islands; it extended to many parts of the world.

I am sure we are extremely proud of Sir Andrew Agnew, and we are honoured that this Institute should have had such a man as its president. (Applause.)

My first duty, and a very pleasurable one, is to invite Sir Andrew to deliver his Presidential Address.

SIR ANDREW AGNEW: The address which I now propose to read has as its title "The United Kingdom Petroleum Industry in War."* Of course my address to-day cannot pretend to be anything more than a general outline of a very small part of what was done by the Petroleum Industry through the machine which it created in the United Kingdom, the Petroleum Board. Throughout my address there will be references to the Petroleum Board, and it will be well to realize that in every case the Petroleum Board means the United Kingdom petroleum industry. The machine was created by the industry and was operated by the men provided from the various oil companies, large and small. In a matter of weeks now, the oil companies will go back to individual trading, and from time to time I am sure that talks about what happened in the war years will take place between individuals whose duties during these years may have kept them quite apart from one another; stories will be told, some amusing and some perhaps pathetic. I hope that the tellers of these stories will be generous with their praise and sparing with their blame. A wonderful task was accomplished, and even looking back I believe that few mistakes were made. In my address the names of individuals are omitted and for a very good reason. Everyone in the team gave of his or her best, and I am glad to have this opportunity of saying "thank you" to everyone.

Sir Andrew then delivered his address.

VOTE OF THANKS.

THE PRESIDENT, proposing a hearty vote of thanks to Sir Andrew for his address, said: There is something very delightful in the process of discovering what someone else has been doing, particularly if there is an atmosphere of secrecy about it. To-night we have been privileged to listen to the disclosure of an amazing piece of history, which has staggered us and will surely merit the attention of future generations. Such planning, such co-operation, and such accomplishment can only have been achieved by minds possessing the greatest flexibility and liberality. Clearly, the men of the Petroleum Board were no amateurs at their job. They were men who had been trained in the arts and mysteries of the petroleum industry. They knew the capabilities of the individual companies and could see at a glance where their respective organizations could be

* *J. Inst. Petrol.*, 1948, **34**, 403–416.

amalgamated into one unit in a time of national emergency. They did it calmly, coolly, and efficiently.

Those of us who live within the petroleum industry have become so accustomed to dazzling displays of ingenuity and progressive ideas that we look for victorious adventures in our leaders. Sir Andrew Agnew has entertained us this evening with an epic worthy of the highest traditions of the industry of which we are fortunate to be members. Throughout that epic Sir Andrew never alluded to himself nor the part he played in it. To himself he was but one of the team. We may be certain, however, that when he was chosen to be the chairman of the Petroleum Board it was because of his powers of leadership and his strong intellectual grasp of the problems which awaited him.

This evening he has incorporated with a noble eloquence, in his presidential address, the difficulties and triumphs of the Petroleum Board in providing a great country and a great fighting force with petroleum products in quantities which were considered to be perfectly impossible at the start—in quantities which we would describe to-day as astronomical.

It was pleasing to read, on April 27, in one of the leading daily papers the expression that the Board had been one of the better instances of close co-operation between private industry and official control. Those modest words convey a great deal, far more perhaps than I can express. It was that co-operation which was so important throughout the war, and to which Sir Andrew has given such force this evening.

We are deeply indebted to you, Sir Andrew, for your presidential address, and I am sure I am voicing the opinion of everyone here when I say thank you very sincerely for it.

The vote of thanks was accorded with enthusiasm.

THE PRESIDENT: That spontaneous applause, I am sure, conveys very adequately, Sir Andrew, our whole-hearted feelings on your gallant effort.

SIR ANDREW AGNEW, responding, said: Thank you very much indeed for the very kind reception you have given my address. It is a pleasure to say a word in praise of the fine lot of people with whom I found myself during the war years. War is a horrible thing; but I can assure you that. living and working as I was during those years amongst men who had one idea, and one idea alone, which was to get the job done, I found myself sometimes even enjoying it. I shall always look back with pride and with a great deal of satisfaction on the fact that I was chosen to be the leader of the wonderful men and women who comprised the Petroleum Board. (Applause.)

ADJOURNED THIRTY-FIFTH ANNUAL GENERAL MEETING.

The thirty-fifth Annual General Meeting of the Institute of Petroleum was resumed at 26, Portland Place, London, W.1, on October 14, 1948, the President, E. A. Evans, in the Chair.

THE PRESIDENT: This is the first occasion on which we have had the privilege at one of our general meetings of welcoming our new secretary, D. A. Hough. I am sure that those of you who have already met him will have been impressed by his charm and modesty; those of us who have known him for only a comparatively short time have appreciated how much better we get to know him as the days go by. To Mr Chilvers and myself he has been a great help, and I am sure I need only commend him to you, for you will be able to make your own estimates of his ability and charm as time goes on.

(Mr Hough was warmly received by the meeting.)

THE SECRETARY read the notice convening the meeting.

THE PRESIDENT: I feel that I really should apologize for calling you together to deal with an adjourned meeting; but we are legally bound to present our accounts so that the Corporate Members may have a true aspect of the finances of the Institute. These accounts cover the year up to December 31, 1947.

From the Balance Sheet it is interesting to note that at December 31, 1947, the capital of the Institute amounted to £6354, and that the General and Revenue Account reserves totalled £5610. That seems to be a very healthy state of affairs.

Turning to the Revenue Account and comparing 1946 and 1947 we see at once that all the costs are increasing, and increasing very rapidly. That has given us a good deal of concern.

However, we derive a little comfort, I think, in viewing our receipts and expenditure in respect of publications. The expenses of publications were £7995, and the receipts were just over £9000.

You will observe that the Library expenses have increased, and that is a very healthy sign. We are all wanting extra books, but there are difficulties in buying them, and it is very nice to be able to come to our own Library when we are in difficulties.

Regarding the item of expenditure, "Fee for Institute Crest," it has been felt for some time that we should have our own crest, and Mr Hyams and his colleagues have spent a good deal of time at the College of Heralds looking for a type of crest which we might adopt.

"Establishment Expenses" include the costs of rent, cleaning, lighting, and lift expenses. It may interest you to know that we have decided to take over the upper portion of Manson House. We now have the first and second floors; the lease was signed yesterday for a period of four years, giving us the use of the third floor also. We hope that this extra space will enable us to extend our activities and give greater comfort and service to our members.

All this is going to involve a good deal more expense. We have realized for some time past that perhaps we are shouldering expenses which are not strictly within the professional orbit of petroleum technologists. I mean, of course, in connexion with standardization of methods of test, research, and various other activities. It has been felt by the industry that they would like to take some part, some responsibility. We have, therefore, made provision for a new grade of members which we have designated "Member-Companies." We have sent out approximately 800 letters to the oil companies and, at their request, to people who make equipment for the petroleum industry, as they feel they are allied to our industry. The letters were sent out as recently as September 29, and we have had already a surprising number of applications for election as Member-Companies. We have fixed the subscription at a minimum of £10 10*s*. Many of the applicants have not been content to give us just that amount; they realize that the work we are doing is worth much more than that, and they have offered 15, 50, and 150 guineas. All this shows that the industry itself is eager to foster the objects of the Institute; and although our Balance Sheet for the current year may be a little less favourable than the one to which we are alluding, I feel that next year will show a very much more healthy condition and we shall be engaged in greater activities.

Gentlemen, the Accounts and Balance Sheet are before you. If there are questions we will endeavour to answer them. I am sorry that the Chairman of the Finance Committee is not able to be here.

DR H. M. DAVIES: I should like to move that the Accounts and Balance Sheet as audited by the Institute's Auditors and showing the position of the Institute's affairs as at December 31, 1947, be approved and are hereby accepted.

I should like to couple with the motion a vote of thanks to the Honorary Treasurer for his able work.

C. L. GILBERT: I second that motion.

The resolution was carried unanimously and the business of the adjourned Annual General Meeting was concluded.

THE INSTIT ETRO

(A Company limited by Guar ot hav

BALANCE SHEE ST D

CAPITAL AND RESERVES.

	£ s. d.	£ s. d.
Capital of the Institute under Bye-Laws 36, 44, and 45 :—		
Life Membership Fund—		
As at 31st December, 1946	899 4 0	
Entrance and Transfer Fees—	£ s. d.	
As at 31st December, 1946	4540 17 9	
Add Receipts during 1947—		
Entrance Fees	213 3 0	
Transfer Fees	17 17 0	
	4771 17 9	
Profit on Sale of Investments—		
As at 31st December, 1946	351 10 11	
Add Profit during 1947	5 0 0	
	356 10 11	
Donations—		
As at 31st December, 1946	326 5 0	
		6353 17 8
T. C. J. Burgess Prize Fund		5 0 0
General Reserve (previously War Contingencies Reserve)		1702 0 11
Revenue Account :—		
As at 31st December, 1946	5960 4 11	
Less Deficit for the year as per attached account	2052 2 2	
		3908 2 9
		11,969 1 4
Subscriptions Received in Advance :—		
Members' Subscriptions for 1948	426 4 9	
Journal Subscriptions for 1948	534 13 11	
		960 18 8
Current Liabilities :—		
Sundry Creditors and Accrued Charges	2617 12 10	
World Petroleum Congress	266 15 2	
		2884 8 0
		£15,814 8 0

Approved by Council :
E. A. EVANS, President.
G. H. COXON, Hon. Treasurer.

REPORT OF THE AUDITORS TO THE MEMBERS

We have obtained all the information and explanations which to the best of our knowledg been kept by the Institute so far as appears from our examination of those books. We books of account. In our opinion and to the best of our information and according to the exp manner so required and the Balance Sheet gives a true and fair view of the state of the Insti for the year ended on that date.

3, FREDERICK'S PLACE,
OLD JEWRY, LONDON, E.C. 2.
16*th July*, 1948.

PETROLEUM.

not having a Share Capital.)

31ST DECEMBER, 1947.

									1946
			FIXED ASSETS.	£	s.	d.	£	s.	d.	£
			stments :—							
			Account of Capital, at cost—							
£61	12	0	3% Conversion Stock, 1948/53	491	12	6				
£25	0	0	3% Savings Bonds, 1955/65	525	0	0				
£00	0	0	3% Defence Bonds	500	0	0				
£67	8	6	2½% Bristol Corporation Redeemable Stock, 1955/65	845	17	7				
£50	0	0	3% Smethwick Corporation Redeemable Stock, 1956/58	151	4	9				
£50	0	0	3% Luton Corporation Redeemable Stock, 1958	151	6	7				
£06	8	3	3% Manchester Corporation Redeemable Consolidated Stock, 1958	845	17	7				
£00	0	0	3% Bristol Corporation Redeemable Stock, 1958/63	597	7	3				
£64	6	6	3% London County Consolidated Stock, 1920	481	10	6				
£00	0	0	3% Metropolitan Water Board "A" Stock, 1963	346	10	7				
£50	0	0	5% Wandsworth & District Gas Co. Debenture Stock	154	8	6				
£25	0	0	5% Great Western Railway Co. Consolidated Preference Stock	105	4	9				
			(Market Value at 31st December, 1947, £5438.)	5196	0	7				*5196*
			h awaiting Investment on Deposit with Post Office Savings Bank	1157	17	1				*922*
							6353	17	8	
			Account of Revenue, at cost—							
£126	14	1	3% Conversion Stock, 1948/53	1200	2	8				
£500	0	0	2½% Defence Bonds	500	0	0				
£475	0	0	3% Savings Bonds, 1955/65	475	0	0				
£000	0	0	3% Savings Bonds, 1960/70	2000	0	0				
							4175	2	8	*4175*
			(Market Value at 31st December, 1947, £4155.)							
			e and Library Furniture at cost, less amounts written off :—							
			at 31st December, 1946	1	0	0				*1*
			d Additions during 1947	192	12	3				
							193	12	3	
			ary Books :—							
			at 31st December, 1946				—			
							10,722	12	7	*10,294*
			ent Assets :—							
			dry Debtors and payments in advance, including Income Tax recoverable to date	1743	12	8				*1222*
			scriptions in arrear (not valued)	—						
			h at Bank on Current Account and in hand	853	19	9				*2099*
			h on Deposit with Post Office Savings Bank—							
			General Account	2227	7	10				*2381*
			World Petroleum Congress	266	15	2				*260*
							5091	15	5	
							£15,814	8	0	*£16,256*

INSTITUTE OF PETROLEUM.

were necessary for the purposes of our audit. In our opinion proper books of account have ned the above Balance Sheet and annexed Revenue Account which are in agreement with the given us the said accounts give the information required by the Companies Act, 1948, in the as at 31st December, 1947, and the Revenue Account gives a true and fair view of the surplus

PRICE, WATERHOUSE & Co.,
Chartered Accountants.
Auditors.

THE INSTITUTE

REVENUE ACCOUNT FOR THE

	£ s. d.	£ s. d.	1946 £
To **Administrative Expenses :—**			
Staff Salaries and National Insurance	4686 17 11		3400
Printing and Stationery	663 16 11		409
General Postages	117 9 6		281
Telephones, Cables and Travelling Expenses	104 16 10		67
Audit Fee	73 10 0		105
Legal Fees	46 2 6		
General Expenses	413 4 5		309
		6105 18 1	
„ **Establishment Expenses :—**			
Rent, less amounts recovered	374 19 4		375
Cleaning, Lighting and Lift Expenses	248 4 7		212
		623 3 11	
„ **Publications Expenses :—**			
Institute Journal Expenses	4083 7 9		3324
I.P. Review Expenses	1637 2 6		
Abstractors' Fees	283 13 0		195
Standard Methods	562 3 2		538
Modern Petroleum Technology	95 3 7		829
Reviews of Petroleum Technology	1088 9 10		
Other Publications	245 12 11		285
		7995 12 9	
„ **Dispatch Expenses**		592 19 1	239
„ **Meetings :—**			
Hire of Hall, Pre-Prints, Reporting, etc.		295 5 11	255
„ **Branches and Sections :—**			
Scottish Branch	46 17 6		
Northern Branch	95 5 0		
South Wales Branch	35 3 6		
London Students Branch	16 7 6		231
		193 13 6	
„ **Sundries :—**			
Library Expenses	159 13 9		29
Subscriptions to Societies	40 7 2		
Scholarship Awards	100 0 0		111
Honoraria	100 0 0		
Fee for Institute Crest	105 0 0		
American Society for Testing Materials	140 0 0		
		645 0 11	
		£16,451 14 2	£11,194

OF PETROLEUM.

YEAR ENDED 31ST DECEMBER, 1947.

						1946
				£	s.	d.	£
By	Members' Subscriptions received for 1947			4822	0	8	4392
„	Members' Subscriptions in Arrear, received during year			119	1	6	269
„	Special Subscription			20	0	0	20
„	Publications Receipts for 1947 :—	£	s. d.				
	Advertising	3327	5 5				
	Journal, I.P. Review, and Abstracts	2401	12 5				
	Other Publications	3288	14 0				5376
				9017	11	10	
„	Interest and Dividends received (Gross)			370	18	0	369
„	Refunds from Branches :—						
	Stanlow Branch			50	0	0	
„	Balance, being Deficit for the Year carried to Balance Sheet			2052	2	2	768
				£16,451	14	2	£11,194

CADMAN MEMORIAL FUND.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1947.

	£ s. d.		£ s. d.
To Balance at 31st December, 1947 :—		**By Balance at 31st December, 1946**	2890 8 7
Cash at Bank on Current Account	128 18 10	**„ Interest received and tax recoverable during year**	81 18 0
£2730 3% Savings Bonds, 1965/75 (Market Value 31st December, 1947, £2784)	2730 0 0		
Income Tax recoverable	113 7 9		
	2972 6 7		
	£2972 6 7		£2972 6 7

We have examined the above Income and Expenditure Account with the books and vouchers of the Fund, and find it to be in accordance therewith. We have verified the cash with Bankers to be in accordance with the balance on 31st December, 1947.

3, FREDERICK'S PLACE,
OLD JEWRY, LONDON, E.C. 2.
16*th July*, 1948.

PRICE, WATERHOUSE & Co.,
Chartered Accountants.
Auditors.

HYDROCARBON RESEARCH GROUP.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1947.

	£ s. d.	£ s. d.		£ s. d.	£ s. d.
To Grants :—			**By Balance at 31st December, 1946**		4780 0 10
University of Cambridge	2000 0 0		**„ Voluntary Contributions received from Members of the Group during the year**	2000 0 0	
University of Oxford	1000 0 0		**„ Contributions from Ministry of Supply**	2000 0 0	
University of Birmingham	1232 2 2				4000 0 0
Bedford College	1525 0 0				
		5757 2 2			
„ Honoraria		1470 0 0			
„ Scholarship Grant		195 0 0			
„ General Expenses		246 11 1			
„ Balance at 31st December, 1947, represented by cash at Westminster Bank, Limited		1111 7 7			
		£8780 0 10			£8780 0 10

We have examined the above Income and Expenditure Account with the books and vouchers of the Fund, and find it to be in accordance therewith. We have verified the cash with Bankers to be in accordance with the balance on 31st December, 1947.

3, FREDERICK'S PLACE,

PRICE, WATERHOUSE & Co.,

We have examined the above Income and Expenditure Account with the books and vouchers of the Fund, and find it to be in accordance therewith. We have verified the cash with Bankers to be in accordance with the balance on 31st December, 1947.

3, Frederick's Place, Price, Waterhouse & Co.

CARCINOGENICITY RESEARCH FUND.

Income and Expenditure Account for the Period ended 31st December, 1947.

	£	s.	d.		£	s.	d.
To Balance at 31st December, 1947, represented by Cash at Westminster Bank, Ltd. . .	2000	0	0	**By Cash received from the Petroleum Board on account of research at Birmingham University**	2000	0	0
	£2000	0	0		£2000	0	0

We have examined the above Income and Expenditure Account with the books and vouchers of the Fund, and find it to be in accordance therewith. We have verified the cash with Bankers to be in accordance with the balance on 31st December, 1947.

3, Frederick's Place,
Old Jewry, London, E.C. 2.
16*th July*, 1948.

Price, Waterhouse & Co.,
Chartered Accountants.
Auditors.

BENEVOLENT FUND.

Receipts and Payments Account for the Year ended 31st December, 1947.

Receipts.

	£ s. d.	£ s. d.	1946 £
Balance at 31st December, 1946		2285 12 3	*1505*
Receipts during 1947 :—			
Subscriptions and Donations	76 1 7		*740*
Interest and Tax recoverable	48 11 4		*41*
		124 12 11	
Profit on Redemption of 3% Local Loans		71 3 0	
		£2481 8 2	*£2286*

Payments.

	£ s. d.	1946 £
Balance at 31st December, 1947	2481 8 2	*2286*
	£2481 8 2	*£2286*

The Balance at 31st December, 1947, was held as follows :—

	£ s. d.
Cash at Bank on Current Account	347 16 2
£650 3% Defence Bonds *	650 0 0
£1450 2½% Defence Bonds *	1450 0 0
Income Tax recoverable	33 1 6
Sundry Debtor :—	
Institute of Petroleum	10 6
	£2481 8 2

* (Market value at 31st December, 1947, £2100.)

We have examined the above Receipts and Payments Account with the books and vouchers of the Fund and find it to be in accordance therewith. We have verified the Investments and the Balances with Bankers and The Institute of Petroleum comprising the Balance on 31st December, 1947.

3, Frederick's Place,
Old Jewry, London, E.C. 2.
16*th July*, 1948.

Price, Waterhouse & Co.
Chartered Accountants.
Auditors.

THE INSTITUTE OF PETROLEUM.

REPORT OF COUNCIL FOR 1947.

MEMBERSHIP.

Details of membership as at December 31, 1947 :

	Total Dec. 31, 1946.	Changes during 1947.						Total Dec. 31, 1947.
		New.	Transferred to.	Resigned.	Deceased.	Transferred from.	+ or −.	
Hon. Members	11	—	—	—	—	—	—	11
Hon. Fellows	3	—	—	—	—	—	—	3
Members	690	34	8	12	9	8	+ 13	703
Fellows	478	19	11	9	11	—	+ 10	488
Assoc. Members	696	81	16	12	2	12	+ 71	767
Assoc. Fellows	—	14	2	—	—	—	+ 16	16
Student Members	200	46	—	3	—	17	+ 26	226
Totals	2078	194	37	36	22	37	+139	2214

Membership has increased steadily, the total membership on December 31, 1947, being 2214, an increase of 6 per cent on 1946. This figure still includes members with whom contact has been lost. Efforts to trace members who are in arrears with their subscriptions have not been very successful and the Election Committee has been asked to make recommendations to Council in this connexion.

Council wishes to draw attention to the broad scope of the Institute and to encourage members of the petroleum industry, who are qualified under the new By-Laws, to apply for membership.

Corporate members are invited to draw the attention of non-members to the advantages of joining the Institute.

The new By-Laws were submitted to a Special General Meeting of Corporate Members on July 24, 1947, and were accepted. These By-Laws became effective as from that date and the first batch of Associate Fellows—a new category of membership—were elected in October.

Deaths.

Council regrets to record the deaths of the following :

	Date elected.	Class of membership.	Obituary notice in *Journal*.
Sir Thos. Holland (Past President)	1913	Fellow	July
Ashley Carter (Vice-President)	1914	Fellow	February
Dr W. Bernoulli	1926	Member	April
N. Betancourt	1934	Fellow	
C. Bihoreau	1935	Fellow	
C. E. Capito	1915	Member	November
A. R. Code	1935	Fellow	November
G. E. Cowlishaw	1936	Member	
O. C. Elvins	1927	Assoc. Member	

	Date elected.	Class of membership.	Obituary notice in *Journal*.
F. A. Flinn	1927	Assoc. Member	May
H. S. Glyde	1944	Fellow	
W. H. Goddard	1939	Member	November
A. Hamilton	1922	Fellow	October
L. B. I. Hamilton	1914	Member	June
F. E. Hunter	1928	Member	
C. E. Keep	1920	Fellow	September
J. W. Knights	1933	Member	
Prof. W. H. McMillan	1939	Fellow	
F. B. Plummer	1922	Member	May
James Smith	1922	Fellow	November
Dr Ing. M. L. Steinschneider	1926	Fellow	April
Prof. W. W. Watts (ex Member of Council)	1916	Member	

Branches and Students' Sections.

The past year has been one of continued activity in all Branches. In addition to a varied programme of papers and social functions, the Branches were privileged to receive visits during the year from R. P. Russell, the Cadman Medallist.

"Suggested Branch Rules" have been approved by Council. Revised rules for the Stanlow Branch—modelled on the standard rules—have been approved by Council, and other Branches are revising their rules on a similar basis.

The final stages were reached in the formation of a London Branch, in place of the original London Students' Section. The Branch will come into being early in 1948.

Publications.

The salient features of the year have been the publication of the first volume of the *I.P. Review*, and the seventh volume of *Reviews of Petroleum Technology*, covering the years 1941–45.

The provision of suitable material for the *I.P. Review* has caused the Publications Committee some anxiety and more contributions from members would be welcomed.

Some 300 copies of *Reviews of Petroleum Technology*, 1941–45 were bespoken prior to publication and there is every indication that this volume will have wide circulation.

The *Journal* has been published monthly, and both *Transactions* and *Abstracts* show increases over 1946.

Standard Methods for Testing Petroleum and Its Products (eighth edition) was issued in February and was out of print before the end of November. Preparations for the ninth edition were completed.

A brochure describing the work and aims of the Institute was printed in the autumn, primarily for public-relations purposes. It is hoped that members will make use of this brochure to introduce the Institute to potential members.

Good progress has been made in restoring the Library. Classification and indexing of books and periodicals has been completed, and Council hopes members will make full use of the facilities provided. The Librarian is always at the service of members. New books are being added to the Library as opportunity occurs.

Standardization.

There are fifteen sub-committees and many panels and working groups engaged on standardization of methods, under the auspices of the Standardization Committee. The work continues to expand although the number of new methods proposed tends to decrease because of the increasing complexity of the newer tests under consideration.

Close co-operation has been maintained with the American Society for Testing Materials and with the British Standards Institution.

Council received with regret the resignation of J. S. Jackson, Chairman of the Standardization Committee, on his retirement, and recorded its appreciation of the valuable services he had rendered. E. A. Evans was elected to succeed Mr Jackson.

Research.

The Research Committee has continued, through its Hydrocarbon Research Group, the promotion of the research on hydrocarbons, with special reference to synthesis and spectroscopic work, in the past year. Considerable progress has been made on the spectroscopic instrument side, and a stage has been reached in which manufacturers are becoming interested in equipment developed under the auspices of this group. On the hydrocarbon-synthesis side, a great deal of interesting chemical work has been done, particularly in connexion with intermediate stages in the synthesis of the hydrocarbons.

The Research Committee has recently taken over the responsibility for certain biological work, started during the war, looking to the evaluation of various petroleum fractions, particularly the lubricating oils and lubricating-oil extracts, from the point of view of their pathological effect. Work under the auspices of this second Research Group appointed by the Research Committee, is being carried out at Birmingham University.

Education.

Further progress has been made and, in fact, the final stages have almost been reached for a City and Guilds Examination in Petroleum Technology which ultimately will be suitable for a technical qualification for the Associate Fellowship of the Institute.

Awards.

The *Cadman Medal* was awarded to R. P. Russell, who delivered the Cadman Lecture entitled "Progress in Petroleumn Research" at the Royal Institution before a large number of members and guests. A very successful Dinner was also held in honour of Mr Russell.

The following *Institute Scholarships* have been awarded:

D. Hammerton . . .	The University, Birmingham
C. A. Fothergill . . .	The Imperial College of Science and Technology

Public Relations.

The Council feels that more should be done to bring the work of the Institute to the knowledge of official organizations, public bodies, the

petroleum industry, and to the general public. To this end a Public Relations Committee has been appointed.

The first step taken has been the preparation of the brochure referred to in the section on Publications.

A memorandum has also been sent to the Ministry of Fuel & Power drawing attention to the facilities the Institute can provide, particularly in an advisory capacity, on matters affecting the petroleum industry as a whole.

FINANCE.

The annual accounts are not yet completed, but provisional estimates indicate that there will be a deficit on the year's working.

The Finance Committee has, therefore, given particular attention to the income and expenditure accounts.

Early in 1946 it was apparent that the post-war period would bring considerable expansion in the activities of the Institute, necessitating additional staff and increased office accommodation. The resultant increased expenditure would not be balanced by the anticipated income.

Ways and means for balancing income and expenditure have been constantly before the Committee. There seems little prospect of doing this with the present income, and Council feels that the first step should be an intensive effort on the part of each member to obtain additional members of the Institute.

Coincident with this, membership subscriptions, and subscriptions to publications, are being reviewed.

BENEVOLENT FUND.

Although, fortunately, no calls have been made on the Benevolent Fund in 1947, Council wishes to draw the attention of members to the importance of keeping up subscriptions and donations to this Fund so that an adequate reserve can be established.

GENERAL.

The House Committee has had under consideration the provision of increased accommodation for the office staff, necessitated by the expanding activities of the Institute. At the same time, consideration has been given to the general question of the location of the headquarters of the Institute when the lease of the present premises expires towards the end of 1948. Negotiations are in progress for a new lease of the premises at present occupied at Manson House, with additional space.

This Committee also has under consideration the introduction of a superannuation scheme for members of the staff.

The Council wishes to record its appreciation of the work of the staff and of the many members of the Institute who have given freely of their time particularly in regard to the activities of the Publications and Standardization groups. The prestige of the Institute stands high and it is due in no small measure to the co-operative spirit shown by all concerned.

By Order of the Council,

C. CHILVERS, *Hon. Secretary.*

OBITUARY.

LT.-COL. H. C. B. HICKLING, C.B.E., D.S.O., M.C.

LT.-COL. H. C. B. HICKLING died at his home in Hampshire on September 13 at the age of sixty-nine. Educated at Haileybury, he entered the mining profession in 1897 and went to Gwanda, Rhodesia, for four years. After serving in Tuscany, Italy, and in Malaya, he joined the forces late in 1914 and served with the B.E.F. He was promoted to command 183 Tunnelling Coy. R.E., in September 1915 and in March 1918 was made lieutenant-colonel commanding R.E. 9 (Scottish) Div. Four times he was mentioned in despatches and was awarded the D.S.O., the M.C., and the Croix de Guerre.

When Apex (Trinidad) Oilfields, Ltd., was formed in 1919, Colonel Hickling took up the position of general manager in Trinidad, a position which he occupied until his appointment to the board of directors. He was also a director of the British Borneo Petroleum Syndicate, Ltd., and of the Usine Ste Madeleine Sugar Co. He was chairman of the Trinidad Oil Companies London Committee, chairman of the West India Committee, a member of the Colonial Labour Advisory Committee, and vice-chairman of the Colonial Employers' Federation.

Colonel Hickling was the first nominated member of the Legislative Council of Trinidad to represent the oil industry and, shortly after his return to England in 1937, he was made a C.B.E. for his services to the Colony.

In the early days of the oil industry Colonel Hickling was largely responsible for developing the wash-pipe method of drilling in oil wells with perforated and screen pipe. In 1934 he contributed a paper to the *Journal* on " Straight-hole technique in Trinidad and its effect on well spacing " and the *Transactions of the Institution of Mining and Metallurgy* (1922–3) contain a paper by him on " Notes on the control of oil wells and the use of screen on the Apex (Trinidad) oilfield."

Colonel Hickling was well known for his drive and organizing ability and for many years has been regarded as an authority on the oil industry of Trinidad. He joined the Institute in 1932 as a Member and was active in the affairs of the Trinidad Branch during his time in the Colony.

L. A. B.